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Applying earned value management in construction project

Thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Technology

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Tiivistelmä

Tällä hetkellä Suomessa työmaan kustannuksia ja aikataulutilannetta seurataan tuotantovaiheessa pääosin erillään toisistaan. Erityisesti Pohjois-Amerikassa mutta myös Aasiassa ja Etelä-Amerikassa projektien seurannassa on jo 1960-luvulta lähtien sovellettu ansaitun arvon teoriaa, joka yhdistää aikataulutilanteen ja kustannusten seurannan.

Tämän diplomityön tarkoituksena on selvittää, onko ansaitun arvon teoria sovellettavissa suomalaiseen asuntorakentamiseen ja voidaanko sen avulla parantaa tai helpottaa projektien seuraamista. Työssä selvitetään, miten ansaitun arvon teoria voidaan ottaa käyttöön projektien seurannassa ja millaisia hyötyjä se voi tarjota nykyisiin seurantamenetelmiin nähden.

Tutkimus koostuu teoreettisen ja empiirisen tutkimuksen perusteella kehitettävästä ansaitun arvon teoriaa soveltavasta projektin seurantatyökalusta ja sen testaamisesta pilottityömailla. Tutkimuksen teoreettinen osuus on toteutettu kirjallisuuskatsauksena ja empiirinen osuus perehtymällä case-yrityksen toimintajärjestelmään ja haastattelemalla henkilöstöä.

Tutkimus osoittaa, että ansaitun arvon teoria on sovellettavissa asuinrakentamisen projekteihin. Kehitetty seurantatyökalu tarjoaa projektin toimihenkilöille yksinkertaisen tavan seurata aikataulutehtävän kertyneitä kustannuksia suhteessa valmiusasteeseen. Haastatteluiden perusteella työkalu tarjoaa entistä tarkempaa tietoa tehtävien etenemisestä ja työpäälliköt ja työmaainsinöörit näkevät työkalun hyödyllisenä omassa työssään

Avainsanat Ansaitun arvon teoria, rakennusprojektin hallinta

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Abstract of master's thesis

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Abstract

Currently in Finland construction project's costs and schedule are monitored apart from each other during the construction phase. Mainly in Northern America but also in Asia and Southern America earned value management has been used as project management tool since 1960's. Earned value management combines the control of scope, cost and schedule together.

The objective of this master's thesis is to examine if the earned value management is applicable in Finnish residential construction projects and if it can offer easier or better way for monitoring projects. Thesis will report how earned value management theory can be implemented and what are the benefits it can offer in comparison to current project monitoring tools.

Research is consistent of developing and testing earned value management application based on information gathered for theoretical framework and empirical research. Theoretical framework is built with literature review and empirical part by familiarizing with case company's ERP-system and interviewing employees.

Based on the research earned value management is applicable in residential construction projects. Project monitoring tool developed offers project's management team simple way for monitoring schedule tasks costs with respect to the state of completion. Based on interviews, developed tool gives more accurate information about tasks progress than currently used systems. Both construction managers and site engineers see the tool useful in their work.

Keywords Earned value management, construction project management

Preface

The inspiration of this thesis originates from the IT-Department of NCC Building Finland. The reason I wanted to grab the EVM to be my subject was construction management course I took a year ago during my exchange semester in National University of Singapore. On that course EVM was presented almost as the holy grail of project management. Of course it seemed too good to be true and I started to wonder why I haven't heard anything about it before. When Ari Törrönen from IT-department mentioned that something could be done with EVM theory the flashbacks from lectures at Singaporean university took over my mind and I know the core of the subject was there. Later I stumbled a bit on defining the exact subject but luckily I had my thesis supervisor Assistant Professor Antti Peltokorpi, thesis advisor Development Manager Jan Lund and IT-manager Ari Törrönen helping me out.

First thanks belong to Antti Peltokorpi for giving me constructive comments and advising me on academic writing. Next I want to thank NCC for financing the thesis and offering me their knowledge and data to support the research process. Huge thanks for Jan Lund for valuable advises and continuous monitoring of my research. I also want to thank Ari Törrönen from IT-department on technical realization of the application and telling what can be done with the information systems and what can't.

I also want to send huge thanks to my friends for offering me peer support but also something else to think on just right ratio. The last and greatest thanks belong to my family for supporting me with this thesis but also with my whole education. They have always encouraged me with my studies and thanks to them I'm on this way.

Espoo 21.8.2018

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Content

1 Introduction

1.1 Backround

Earned value management (EVM) is a project management technique for measuring and assessing project performance and progress. It integrates the project's scope with the cost along with the schedule to form the performance measurement baseline. EVM monitors three key dimensions for each project or part of the project; planned value, earned value and actual costs. These three key parameters are often presented as cumulative graphs for monitoring and reporting the project. (Snyder, 2014)

EVM emerged as a financial analysis speciality in United States Government programs in the 1960's, but it has since become a significant branch of project management and cost engineering. EVM has been noted to have strong positive contribution to project success. (Fleming and Koppelman, 2005) One of the strengths of EVM is that the principles can be applied to all projects in any industry (Snyder, 2014). Thus, EVM is widely used in many different kind of projects including construction in U.S., Canada, Australia and Japan. But in Europe there are only few recorded applications in construction field. (De Marco and Narbaev, 2013) Currently there are no recorded applications from Finland available and as a consequence the benefits offered by the EVM methodology are not reported.

The case company of this thesis, NCC Building Finland wanted a new illustrative way to measure project performance and progress and integrate the schedule and cost performance into a single measure to offer a simple indicator for the progress of the project. EVM is reported to offer cost and schedule integrated data to support project management and therefore it might be suitable solution for the need of new tool.

This thesis will be conducted for NCC Building Finland's unit of residential construction in capital area of Finland (Asuinrakentaminen, AR). NCC Building is a multinational construction company and it is one of the largest companies operating in Finnish construction field. Year 2016 NCC Building Finland had a total of 1 539 employees and revenue of 684 million euros (Taloussanomat, 2018). NCC primary constructs housing and offices, but also public premises, such as schools and hospitals, commercial buildings and refurbishment projects (NCC, 2018).

1.2 Research objectives and scope

This thesis will study how earned value management can be implemented in construction project and what kind of benefits it can offer for the supervisors of construction site. EVM theory and the information requirements for generating viable graphs will be studied. After assessing the information demands will be studied how the information can be processed and collected automatically from the current information systems of the company.

The final objective of the Master's Thesis is to generate a system that automatically collects data from company's different information systems and generates the EVM graphs of planned value, earned value and actual costs and gives alerts to construction site supervisors of certain deviations. One target of the created system is to collect data of differences between planned value, earned value and actual costs and search the reasons for deviation to improve the forecast. Information collected about deviations is supposed to help on creating more viable schedules and realistic estimations of costs.

The main research question is:

- How earned value management can be applied in construction project?

And the sub questions are:

- How costs, schedule and progress of project are currently estimated and monitored?
- How EVM key parameters can be automatically determined for a project?
- How EVM could improve cost and schedule monitoring?

Since the case company and more precisely case unit is specialized in residential construction the empirical research covers only residential projects. Therefore this master's thesis will be focusing only on residential building projects. This thesis covers only the production phase budget and schedule planning and monitoring because EVM is closely tied to production phase. Even though this thesis covers only residential projects it can offer results that are applicable in other construction project types too.

1.3 Methodology

This thesis is a constructive research. Constructive research method is widely used in technical sciences, clinical medicine and operations research (Kasanen et al., 1993; Lukka, 2006). Constructive research approach is determined to be a problem-solving method that both relies on different research tools and is also associated with interpretive epistemology, positivist epistemology and empiricism. Construcive research design is question-driven logical sequence connecting initial research questions to empirical data and finally to its conclusions. The target of constructive research is to produce solutions to both theoretical and practical problems. (Oyegoke, 2011) An essential part of the constructive approach is to combine the problem and its solution with accumulated theoretical knowledge. The novelty and the actual working of the solution have also to be demonstrated in the research. (Kasanen et al., 1993; Lukka, 2001, 2006) The constructive approach may be characterized by dividing the research process into six phases. The order of these phases can vary from case to case:

1. Find a practically relevant problem which also has research potential.
2. Obtain a general and comprehensive understanding of the topic.

3. Innovate, i.e., construct a solution idea.
4. Demonstrate that the solution works.
5. Show the theoretical connections and the research contribution of the solution concept.
6. Examine the scope of applicability of the solution. (Kasanen et al., 1993; Lukka, 2001, 2006)

Understanding of the topic is built with literature review and empirical research including interviews and exploring case company's enterprise resource planning (ERP) system. As a solution idea an application of EVM is built, presented and tested on three construction projects. Feedback of the application is collected by interviewing personnel of the test projects. As a conclusion the applicability of the solution is discussed.

Previous researches and other existing literature for example project management text books offer a theoretical framework for cost and schedule planning and control and utilization of EVM. The main purposes of literature review is to explain how costs and schedules are currently managed and how EVM can be applied and implemented in construction projects and what are the benefits it can offer. The fundamentals of cost and schedule management and EVM are mostly studied from textbooks. Previous researches are the main sources of information on familiarizing with the implementation process on construction projects and benefits of EVM.

To find academic articles Google Scholar was the primary search engine along with the Aalto-Finna search portal. Throught Aalto SFX access to publisher databases of scientific articles like "Elsevier", "ProQuest", "ScienceDirect", "ASCE library", and "ResearchGate" was received.

The target of empirical research is to investigate how cost and schedule management is accomplished currently in the case company. In the empirical research it is also examined if there are any EVM-like application used to monitor project's progress. Feedback of the created application is also collected as a part of empirical research.

The empirical research is composed of three parts: familiarizing with the ERP-system, interviewing case company personnel and testing of the application created. ERP-system includes the fundamental manual for cost and schedule planning, monitoring and controlling. To standardize the procedures everyone should work according to the manual offered in ERP-system. It can be said that ERP-system tells what should be done and how. The interviews are arranged to investigate how cost and schedule management is actually carried out on more specific level. The application and the results of test projects are presented to construction mangers and site engineers and their feedback is collected.

Interviewing process was semi-structured. Semi-structured interview questions do not have specific order or form and the interviewer can change the order and form of questions. The interviewee can answer the question using own words and there are no ready answers to choose from. The interview can be described as a conversation between interviewer and interviewee. (Hirsjärvi and Hurme, 1988, 2000) Because of the nature of the semi-structured interview each interview is unique (Saunders, 2011). Interviewing by using this method gives interviewee a possibility to be creative and guide the discussion to desired direction (Hirsjärvi and Hurme, 1988). The main benefit of this interview type is openness. The question remain the same for every interviewed person but the whole interview is like a flow of conversation. Since the structure isn't specified in advance new opinions and points may appear. Also this interview type gives a possibility for interviewees to explain their opinions and visions by using their own words. (Saunders, 2011)

All the interviews were held at the NCC office or at the construction site offices. The subjects discussed in the interviews were told to interviewees beforehand, but explicit questions were not sent in advance. The subjects discussed and questions asked were specified based on the role of the interviewee. In the beginning of the interview the subject of this thesis was briefly presented and discussed. The interviewees also told about their current role and background in the company and construction business. At first the interview proceeded according to question list, but some additional and detailed questions were asked based on the answers of interviewee. In the end of the interview was possibility to return to some subjects discussed before or continue discussion on some other subject that interviewee saw relevant. For site engineers and project managers the first test version of proposed EVM application was presented at the end of the interview and they were asked to comment how they would use it in their work and if it offers something new information.

In this thesis the roles of interviewees are relevant to present because the role defines what are the relevant questions to ask and the role is assumed to affect on their answers. The names and ages of interviewees are irrelevant and are not presented. The interviewees, their duties and the date of interview are presented in a Table 1.

Table 1: Interviewees, their duties and dates of interviews

Interviewee	Duty	Date
I1, I2	Site engineer	5.6.2018
I3	Construction manager	5.6.2018
I4, I5	Site engineer	6.6.2018
I6	Cost engineer	6.6.2018
I7	Strategy manager	6.6.2018
I8	Site Engineer	7.6.2018
I9	Purchase Manager	7.6.2018
I10, I11	Construction manager	8.6.2018
I12	Development manager (finances)	15.6.2018

All the interviews were recorded and the tapes were analysed afterwards. Because the half-structured interview is more like discussion and can last for long times the tapes include a lot of irrelevant data. Because of the large amount of recorded information, the structuring happens after interviews. (Hirsjärvi and Hurme, 1988) Since there were only 12 interviews larger scale comparison analysis was not performed. Instead the main points were gathered by themes in order to form the general way of working.

The proposed solution for the research problem is innovated based on theoretical and empirical information gathered. The proposed solution was applied in three ongoing construction projects. The idea and first version of the created application was presented to construction managers and site engineers during their interviews. They were asked to comment the application as a tool for project management and evaluate the benefits it could offer if used regularly. In the interviews of tests project's construction managers and site engineers they were also asked to evaluate the validity of the data the application was offering and analyse the results.

2 Theoretical backround

This chapter contains the theoretical background as as it is described in literature. Theoretical framework is consistent of production planning, project's cost management and earned value management theory.

Production planning is reviewed from the location-based point of view. Project scheduling chapters include basics of schedule planning and fundamentals of schedule control and reporting. Similarly project cost management is composed of the basics of construction cost estimation, budgeting and cost monitoring and control.

Chapters discussing earned value management include the basics of earned value management theory. Recorded advantages and disadvantages of earned value management are reviewed and schedule management theory earned schedule is presented as an expansion to EVM theory. The implementation steps of EVM recommended by Project Management Institute are underwent and some recorded applications of EVM in construction projects are summarized. The EVM theory is finalized with study of adapting EVM to location-based management system.

As a conclusion to literature review the last chapter summarizes the results of literature review as answers to research questions from the theoretical point of view.

2.1 Production planning and control

Scheduling of the projects is the most important part project's production planning and the foundation of resource management (Artto et al., 2006; Junnonen, 2010). Schedule management of the production forms the basis for other production planning and reveal the defects and deviation from plans effectively (Junnonen, 2010). Projects Schedule management is composed of schedule planning, schedule monitoring and controlling. (Artto et al., 2006) Staying in the planned schedule is the most important actor of project's success. Thoroughly planned schedule can diminish costs, increase the quality of work and working safety. (Junnonen, 2010) The target of project's schedule management is to ensure that the project can be completed in agreed time frame. (Artto et al., 2006)

Production plans will get more accurate as the production proceeds and new information comes available. In the beginning of a project general schedule is created and during the construction process more accurate construction phase schedules can be planned. The execution of a single tasks is ensured by using task schedules or weekly schedules. In scheduling process the higher level plans determine the targets of lower level plans. (Junnonen, 2010)

General schedule determines the procession of the whole project and shows the critical tasks. General schedule determines the main resources and thus it works as a guideline for planning workforce, purchases and delivery dates. All the more accurate level schedules must be based on general schedule and the targets should be set so that general schedule can be met. General schedule works also as schedule communication tool between all the parties involved in construction project. (Junnonen, 2010)

Scheduling is currently done by following either one of the two main methodologies. The main methodologies are activity-based scheduling and location-based scheduling. These two methodologies in turn include several varying methods and techniques, but are commonly they are associated with two principal scheduling methods: Critical path method (CPM) and either line-of-balance or flowline. (Kenley and Seppänen, 2006)

Currently activity-based scheduling is the dominating scheduling technique worldwide. It was first developed in the 1950s. The activity-based techniques rely on the construction of logical network of activities with complexity of four levels: deterministic (for example CPM), propabilistic (PERT), generalized activity networks and the critical chain method more recently developed. Common to all of these activity-based methods is the fundamental logical structure of the model. It is a topological map of discrete activities joined by logical relationships. Activities are free to move in time as long as they maintain their logical relationship with their predecessors and successors. (Kenley and Seppänen, 2009) There is a widespread use of Critical Path Method in construction projects and for example in United States it is commonly a contractual requirement demanded by owners. (Olivieri et al., 2016)

Location-based planning and management methods have been widely adapted in Finland in construction since 1980's. To Finland the methods were brought and adapted to commercial construction by professors Kankainen and Kiiras from Helsinki University of Technology. Researches confirmed that production planning according location-based management system increases productivity and decreases waiting hours of direct labour and subcontractors. (Kenley and Seppänen, 2006)

To improve the project planning and especially scheduling skills of the Finnish industry new research programs were started in the end of 1990's by Professor Kankainen's research group. The results of their research included tools to support location-based control. Tool created included task planning, control charts, check list to asses a schedules feasibility and new contracts. The result of their research were used in developing a software to be used as a location-based management system planning and control tool. (Kenley and Seppänen, 2006)

As a result of two decades of research a complete schedule planning and controlling methodology based on managing schedule risk has been developed. One of the most important and long term result of this effort was building productivity databases together with the largest contractors in Finland. These databases are continuously updated and used by all parties. They include work method descriptions and good target level productivity information for labour and material consumption information. The database is maintained by the Confederation of Finnish Construction Industries. (Kenley and Seppänen, 2006)

Location-based management system (LBMS) is lean production planning and controlling tool. LBMS aims to decrease waste, increase transparency, improve predictability and improve flow. Location-based management system is widely adopted in Finland and there is no tradition of using CPM schedules. (Olivieri et al., 2016)

The term location-based describes this methodology because a project may be modelled including individual packages of works called activities into a connected whole entity called a tasks which represents the aggregation of activities in multiple locations. Topological CPM-like maps can be then modelled by linking tasks to each other by using logical relationships. The focus of the method is on the task moving through production units called locations and the project data sits in both the task and the location. (Kenley and Seppänen, 2009)

Location-based management is based on assumption that planning analyzing and controlling work flowing through the smaller location levels instead of the whole project level adds value. The locations contain project data on a level that is easy to monitor and analyze. Location-based schedule planning is concentrated to preserve the work flow throught the locations and disable breaks on work flow. The priority of location-based planning is to plan to ensure the productivity. (Kenley and Seppänen, 2009) In other words the schedule must be planned so that work does not wait for workers and workers do not wait for work. (Seppänen et al., 2010)

2.1.1 Location-based schedule planning

Locations are the foundation of location-based planning and control system. Locations of the project are hierarchically organized and defined by a location breakdown structure (LBS). (Kenley and Seppänen, 2006; Seppänen et al., 2009). LBS has many similarities with the work breakdown structure (WBS) (Kenley and Seppänen, 2006). Each of the location hierarchies has a different purpose for planning and monitoring. The highest level is used to optimize construction sequence, where the sequence timing can be changed to optimize overall production. The structures of such sections are independent of each other for example, individual buildings or structurally independent parts of large buildings. The middle levels are used to plan production flow in the structure. In residential construction project's LBS, floors can be considered as middle levels locations because they are usually finished one at a time. The lowest level locations are usually such small that only one contractor can effectively work in the area. For example, apartments, individual retail spaces or corridors can form the lowest level in the hierarchy. The lowest level locations should be able to be monitored accurately. (Junnonen, 2010; Kankainen and Sandvik, 1993; Kenley and Seppänen, 2006; Seppänen et al., 2009) The location breakdown structure is usually presented as the flowline view's vertical axis, with the location hierarchy projecting horizontally from highest to lowest level (Junnonen, 2010; Seppänen et al., 2009).

Each task is defined at a specified LBS hierarchy level. For example the structure is built one floor at a time, thus its logical hierarchy level is floor. Finishes are done one apartment at a time and the logical hierarchy level is the apartment level. It is important not to apply inappropriate detail to an activity, for example there is not point in defining structure tasks at an apartment level, as apartments do not exist at the time of creating the structure. (Kenley and Seppänen, 2006, 2009)

Quantities are an essential part of location-based scheduling and in particular the internal logic of a task is formed based on quantities (Kenley and Seppänen, 2006). The LBM planning method optimizes the production rates to achieve continuous resource and work flow. If quantities or productivities are unknown, the actual durations are guesses at best and continuity over6 the locations can not be assured. (Seppanen et al., 2005a) Quantities drive the production process and determine the amount of work to be done in each location. The bill of quantities determined for a task define the work that must be finished before a location is considered completed and the crew may continue to the next location. Many different items of work may be undertaken in a single work package, or a sequence of work packages in a summary. (Kenley and Seppänen, 2006)

After a location breakdown structure is determined, quantities can be estimated by location (Junnonen, 2010). Quantity-based estimating can be approximated if actual quantities are not known. Early approximation can be done using the total duration data, resource-loaded duration data or by using simple quantities like floor area. While approximation methods are never as accurate as a proper measure, they offer a rapid and useful solution to form indicative schedule for early estimate. (Kenley and Seppänen, 2006) While quantity surveyors are engaged on a project, they may manually prepare a detailed measure of project quantities (Junnonen, 2010). Prepared bill of quantities (BoQ) offer a very reliable basis for scheduling. However such bills of quantities rarely include the location breakdown. Quantities may still be used by dividing the quantities according to elemental quantities such as floor area. This can only be an approximation as quantities rarely strictly follow elemental quantities, but nevertheless it is a quick way to generate schedule from a BoQ. (Kenley and Seppänen, 2006)

Modern technology has the potential to impact on the quantity surveying profession by automating the production of accurate measures of quantities for building projects. Systems can produce quantity measures of varying accuracy, softwares now have the capacity to produce complete and accurate measure of all quantities for a project and to include location information for the quantities, thus providing quantities according to LBS. The methodology is to shift the effort in measuring from manual take-off from drawings of a project, to building object oriented models of the project using 3D modelling software and then create location-based measures automatically. (Kenley and Seppänen, 2006)

The actual schedule planning is began with a bill of quantities of the project and the first task of a planner is to combine relevant BoQ items into logical packages to form tasks (Kankainen and Seppänen, 2003). The task is the method of control and is the container for data which relates to the production of the project. The data task contains includes labour resources, time and cost. (Kenley and Seppänen, 2009) Items can be joined into a single task if the work can be done with single crew, has the same dependency logic outside the task and can be completely finished in one location before moving to next location (Kankainen and Sandvik, 1993). The next role of the planner is to ensure that all relevant quantities are allocated in tasks. This procedure makes sure that anything relevant is not left out of the schedule and allows ways of controlling a project as well as handling change orders and claims. (Kenley and Seppänen, 2006)

Labour consumption is a determined property of each individual BoQ item composing the task. The consumption rate indicates the amount of worker or machine time that it takes to produce one unit of each item. The values of consumption rates may be based on historical data, which may be collected by the quantity surveyor or estimator, or it can be found from general productivity database. (Kenley and Seppänen, 2006) In Finland labour consumption proposed by Ratu are often used (Junnonen, 2010). The total quantity of worker hours needed to complete a location is the sum of the individual hours for each BoQ item in the task, which are calculated by multiplying the quantity of the location by the labour consumption rate for the item. (Kenley and Seppänen, 2006)

The total hours of work required for the task does not describe how the work is to be performed, because there is no information about the resource available to make the calculation of duration. In practise, tasks use crews which may have varying compositions of resources and which when combined with labour or plant consumption rates, yield an effective production rate which can then be used to calculate the duration for the task for given location. Many tasks have an optimal crew composition which will more efficiently perform the work. Therefore, work can best be speed up or slowed down by adding or reducing resources of the task in multiples of the optimal crew size. (Kenley and Seppänen, 2006) The total hours needed to complete the task are divided by the number of resources planned to be used to get the duration in hours, and then divided by planned shift length to get the duration in days (Kankainen and Sandvik, 1993; Kankainen and Seppänen, 2003). Resources may vary in their contribution to the total effort of the crew as well as the difficulty of location may vary between locations and due to learning. Therefore difficulty factors or productivity factors are applied to the entire task or to specific locations. (Kenley and Seppänen, 2006)

After the tasks are determined the dependencies between tasks need to be formed. Schedule tasks have generally two kinds of dependencies. Internal dependencies are the dependencies between the locations of the task. They are created according to the place completion order determined. External dependencies are dependencies between schedule tasks. (Kankainen and Seppänen, 2003) Kenley and Seppänen (2009) introduced a term layered logic to describe the location-based system's logic combined of five different layers of logic of Location-based system. The layered logic involves the external logical relationships between activities within location, external higher level logical relationships between activities driven by different levels of accuracy, internal logic between activities within tasks in related locations, phased hybrid logic between tasks in related locations and standard CPM links between any tasks and different locations.

Time lags and buffers are not an additional layer of logic, but they are critical part of layered logic. Lags are the required fixed duration of logical connection between two activities or tasks. For example curing time and start-up delays are usual lags. Buffers are additional time allowance meant to protect the schedule and are intended to absorb minor variations in production. (Kenley and Seppänen, 2009)

After the task dependencies are set the optimization of schedule can begin. The purpose of optimizations is to minimize the effects of task duration variability. Optimization can be done using two main tools; adding buffers and synchronizing tasks. Synchronization means the tasks are planned so that schedule tasks proceeding and succeeding each other have the same speed. To change the speed the resources of the task or content of work must be changed. Startup delays and vertical space buffer are added between tasks. The desired duration of the projects and agreed risk level set the length of start-up delays and buffer sizes. (Kankainen and Seppänen, 2003) In basic project's, the normal values used in Finland are start-up delay of two weeks and space buffer of two floors (Kankainen and Sabdvik, 1996). In special projects, three weeks start-up delay is often used due to greater uncertainty (Kiiras, 1989).

To check the feasibility of the schedule Monte Carlo risk simulation can be ran. The uncertainty in the prerequisites of the task is reflected by starting time distribution and the uncertainty associated with production rate of the task is reflected by duration distribution. (Kankainen and Seppänen, 2003) Based on Finnish research every project gains benefit from risk analysis during master schedule planning. In one research project, four construction projects were analyzed with Monte Carlo simulation tool and the schedules were re-planned based on simulation result. The re-planned schedules had much lower risk level and much higher quality. Changes done based on risk analysis included changing the construction order of building's sections, re-planning overlapping interior works and rescheduling the tasks most prone to disruptions. (Kolhonen et al., 2003)

2.1.2 Location-based control

Location-based control assumes that in the planning phase the productivity is maximised, and an optimal balance between risk and duration is found and the plan is feasible to implement. It remains therefore to ensure that the work is undertaken such as achieve this plan. Deviation from the plan will result in a less than optimum solution. The location-based control system generates on-time response to management through visualisation of any problems before they occur. Forecasts are used to constantly remind management that a problem remains unsolved and that information is available to help them take the informed control actions. (Kenley and Seppänen, 2006)

The location-based control model needs to provide accurate data sufficient to differentiate performance deviations from changes in circumstance. The sources of deviation may include: quantity changes, start-up delays, production rate deviations, discontinuities and working out of sequence and production prerequisites. (Junnonen, 2010; Kenley and Seppänen, 2006) Tracking accurate data and having a system with flexibility to manage changes in implemented production plan will lead to better management of the perquisites of production, the availability of suitable resources and more detailed look-ahead planning during construction. (Kenley and Seppänen, 2006)

The location-based control model utilizes production information of four stages. The stages used are baseline plan, current, progress and forecast. LBMS tracks data in these four stages using two sets of tasks: Schedule tasks and detail tasks. Schedule tasks are the tasks which make up the baseline schedule. (Seppänen et al., 2010, 2009) Detail tasks are the exploded current plans for the actual production of the baseline task. Detail tasks always belong to a single schedule task and make up the current view of schedule task. (Kenley and Seppänen, 2006)

Baseline stage provides the founding set of project data, such as committed plan for the project, against which all subsequent performance is compared. The baseline plan cannot be changed, unless a new baseline is established, and it constrains the current plan. The location based baseline model uses location-based quantities and control tasks to plan the work. The baseline plan is generally used as attachments to contracts to engage subcontractors to schedule, to prepare procurements and plan delivery schedules. To achieve these objectives the start and end dates should be reliable to within one week accuracy. (Kenley and Seppänen, 2006; Seppänen et al., 2009)

Current stage -schedule functions in a similar way as the baseline schedule, but it recognises the need to update the schedule according to new information which has come out after the baseline plan was set, including both changes in project data and more detailed construction planning (Seppänen et al., 2009). The current plan is changed whenever new information is available. This new information can include information about resource availability, prerequisites of production, quantity changes or change of logic. However, even if there are changes, the original baseline constrains the finish dates in each location.

(Kenley and Seppänen, 2006)

The location-based control model establishes the mapping between these two planning stages, using updated current location-based quantities and a set of current stage tasks called detail tasks to manage the changes involved in current stage planning. Detail tasks also consist of detail activities in each location. (Kenley and Seppänen, 2006)

During the actual production phase the baseline and current information is gradually augmented by progress information. This information highlights deviations from the plan and it is used to calculate the forecast and is critical in the later evaluations of the quality of the original schedule. Status information should be tracked by location. (Kenley and Seppänen, 2006; Seppänen et al., 2009) More benefit is gained if progress is tracked for all components of the planning and control system including actual quantities, actual resources, actual shift length and days off, actual start and finish dates. The information collected can be used to calculate the actual resource consumption and production rate. (Seppanen et al., 2005a; Seppänen et al., 2010)

Actual quantities reveal deviations from the current quantities which can be critical if they are expected to repeat in other locations. Quantity deviations can result from errors in measurement, an undocumented variation and an attempt by a sub contractor to charge for work not included in the contract. Deviation of current quantities should prompt immediate effort to identify the reason for the deviation and to prevent it from occurring again in subsequent locations for that task. In addition, it provides information for the schedule and cost forecasts and for calculating the actual resource consumption and production rates. (Kenley and Seppänen, 2006) Actual resources should be tracked because deviation from plans can forecast future problems and explain schedule delays. To get realistic information about productivity, the actual resources need to be distributed to detail task and locations. Actual shift length and days off are important because resource consumption rates that emerge from simply calculating actual durations using the planned shift length will be incorrect in the event that workers have been on holiday or have been working overtime or weekends. (Seppanen et al., 2005a)

A daily level of accuracy is usually enough for the calculation of actual start and finish dates for a location. For every short duration activities this will distort the resource consumption rates but this will usually correct after enough locations. While a greater level of detail may be desirable, data collection requirements must also be realistic or the method may not actually be implemented on construction sites. It should be known when individual locations were actually started and when they were finished, otherwise it is not possible to plot progress information to flowline diagrams or to calculate actual production rates or resource consumption rates. (Seppanen et al., 2005a)

Interruption to work longer than a day should be recorded. Otherwise, the actual consumption and production rates will be overly pessimistic, providing misleading forecasts. The level of interruption is also a good measure of success in location-based control, because the aim of location-based control is to minimize interruptions. (Kenley and Seppänen, 2006)

Monitoring of these items should be made the most accurate planning level. Effectively this is the chosen location level of the detail task. (Kenley and Seppänen, 2006)

Forecasting is a process which utilizes the best currently available information. In the early stages of the project, the original plan can be used, the forecast is updated when new information comes available. During production the actual recorded production rates should be used as the basis of forecast. (Kankainen and Seppänen, 2003; Kenley and Seppänen, 2006) The current and progress data can be used to calculate forecast to predict the total effect of schedule deviations and variations, and therefore reveal problems. Forecasts should assume that production will continue with the achieved production rate unless control actions are taken. Forecasts empower management to react to problem early enough to take effective action and to provide the data required to support control action decisions. (Seppanen et al., 2005a; Seppänen et al., 2009)

Location-based control actions are the steps that are taken to recover from deviation in order to prevent interference or project delay. Control action planning resembles rescheduling detail level tasks. The goal for control action planning is to find a feasible solution to prevent interference. (Kankainen and Seppänen, 2003) The actions that are available to avoid interference are: changing the number of resources, changing shift length or working overtime, changing the location sequence, splitting a task, removing or switching the technical dependency, increasing productivity by reducing non value-adding activities and shifting the start date of succeeding task to make that task continuous. (Seppanen et al., 2005a)

With control actions it is the forecast to be adjusted directly to correspond with planned control actions, rather than the plan. The plan is not changed because the fact that there was a deviation in the first place would then become hidden. By adapting the forecast instead of the plan, management accepts that there was a deviation but commits to action to restore the original plan. (Kenley and Seppänen, 2006) It is also desirable to maintain a log of the control actions taken. A forecast which has been adjusted with any control actions becomes the location-based look-ahead plan. (Seppänen et al., 2009)

besides using measured data to count forecast and to make justified control actions, it can be used in pre-planning of upcoming projects since it offers the latest information about productivity. Even though construction projects are unique the actual work is often same in all projects. Therefore the recorded production rates can be used in any other project if the task has the same content of work. (Seppanen et al., 2005a)

2.1.3 Location-based reporting

Location-based planning and control is heavily influenced by graphical techniques of representation. In addition to the use of traditional Gantt Charts, LBMS makes extensive use of flowline diagrams and control charts. (Kenley and Seppänen, 2006)

The flowline representation is the primary communication method for LBMS. A singe view is able to project a great deal of information about the plan for the work, particularly the continuity and planned breaks. Flowline is even more effective representation tool when used in the control phase. Here the inclusion of lines for actual work highlight the actual circumstances through the entire history of the project. Forecasts predict the likely outcome given current rates of progress. In the control mode, an experienced user is able to quickly read the history of the project, compare it to the plan and interpret the future consequences. (Kenley and Seppänen, 2006)

While a flowline can be rapidly read by experienced users, the control chart is extremely effective for communicating dates, work sequences and progress performance for individual tasks. A control chart is a matrix of tasks and locations. Tasks are on horizontal axis and the location breakdown structure on the vertical axis. Each sell of the matrix shows the status of a task's location. Status can be shown with color codes and number in the cells. (Kankainen and Seppänen, 2003) To make the control chart work effectively, customized control charts should be provided to the various superintendents and subcontractors for the site. (Kenley and Seppänen, 2006)

Actual data can be compared with either the baseline or the current plan formed by detail tasks. Each approach has a merit, depending on what needs to be communicated. The client is generally interested in seeing the progress against the originally approved baseline. Subcontractors who commit to detailed schedules should have a control chart which compares their progress against the detailed schedule. (Kenley and Seppänen, 2006)

Those responsible for a given task are able to compare the planned dates with actual dates, and colour coding provides rapid feedback about project status (Kankainen and Seppänen, 2003). This form of communication is ideal for project site meetings, where responsible individuals can be rapidly held to account for their lack of progress by reading the colour coding of the tasks. However control chart should not be used as a controlling tool, as it is a static report. Controlling requires knowledge of production rates and available locations and thus flowline diagrams and forecasts should be used. (Kenley and Seppänen, 2006)

2.2 Project cost management

Construction cost management includes several of functions such as estimating, scheduling, cost control, resource costing and financial control. All these functions include large quantity of data with many complex interrelationships (Perera and Imriyas, 2004). Cost estimating is a function that occurs throughout the life cycle of the project to reflect scope, design, constructibility and performance changes. Cost management is fundamentally critical to all active stakeholders. Cost monitoring and control then again are proactive and used to predict the final outcome of a project based on actual costs, which allows preventive or corrective actions to avoid variations in final cost. Cost control techniques may differ on some projects, depending on the type of contracting strategy used. (Project Management Institute, 2016)

2.2.1 Construction cost estimation

Cost estimation is process of developing an approximation of the monetary resources needed to complete project activities. The key benefit of this process is that it determines the amount of cost required to complete project work. (Snyder, 2014) Cost estimates are the foundation for project's profitability calculations and during the construction phase estimate is considered as the reference line for the cost control. (Pelin, 2011)

Costs are estimated for all resources charged from the project. Construction cost estimates include direct and indirect costs. Directs costs are those that are directly attributable to a specific scope of work. Indirect costs are those costs that cannot be directly associated to a specific scope of work and are allocated equitably over multiple scopes of work in a single project. (Project Management Institute, 2016) Cost estimates are a predictions based on the known information at any point in time and get more accurate gradually as the design process progresses. (Pelin, 2011) Cost estimates include the identification and consideration of costing alternatives to initiate and complete the project. Cost trade offs and risks should be considered, such as make versus buy, buy versus lease and the sharing of resources in order to achieve optimal costs for the project. (Snyder, 2014)

The information available defines the used cost estimation method. The more detailed the project design are the more accurate cost estimate can be established. Analogous estimates are also referred to as preliminary, conceptual, top-down, order of magnitude and rough order magnitude. Generally analogous techniques are customized for industrial sector through the use of industry-specific historical data. Some of the notable analogous techniques used in construction are capacity-factored and equipment-factored estimating. Industry publications provide estimating data. (Project Management Institute, 2016; Snyder, 2014) In Finland Haahtela provides information to help estimating based on historical data (Pennanen et al., 2011). Parametric estimating uses a statistical relationship between relevant historical data and other project specific variables to calculate a cost estimate. The construction industry frequently uses software applications that provide a local industry specific cost database and available cost information offered by specialized publications and professional associations. (Project Management Institute, 2016; Snyder, 2014)

Bottom-up techniques are the estimate tool of choice when the detailed project design comes available. A prerequisite to a bottom-up estimate is a clearly defined and detailed scope including documents such as a WBS, issued for construction drawings and specification. The detailed estimating technique results in a transparent and structured estimate for the project that is more accurate and reliable. (Project Management Institute, 2016) Cost estimates are aggregated by work packages in accordance with the work breakdown structure (WBS) and are often referred to as construction work packages. These work package's cost estimates are aggregated for the higher component levels of the WBS, such as control accounts and ultimately, for the entire project. Work packages include all labor, material, equipment and subcontractor costs. (Pelin, 2011; Project Management Institute, 2016) Construction projects in Finland generally utilize nomenclature called "Talo 80" as WBS. Talo 80 divides the elements of a project in ten main groups. (Enkovaara and Heikki-Jeskanen, 2008) "Talo 80" has also newer versions "Talo 90" and "Talo 2000".

Each control account is assigned a unique code or account number that links it directly to the performing organizations account system. A cost breakdown structure is sometimes developed as a mapping tool between the project WBS and the organization's designated code of accounts to aid reporting costs. (Project Management Institute, 2016) In Finland the control account numbers are often determined by the "Talo 80" -nomenclature as well as the WBS is. Some companies use their own nomenclature systems. (Enkovaara and Heikki-Jeskanen, 2008)

Most estimates are based on a similar project basis. The basis of estimate is an important document that helps drive estimate accuracy. the document provides supporting documentation with a clear and complete description of how the estimate was derived, including but not limited to the list of included information, for example, the level of accuracy, exclusions and assumptions. Past project lessons learned aid in the estimation of the next project by providing historical cost data. Especially the actual cost of activities is one of the most valuable asset for a construction industry organization. (Project Management Institute, 2016) Sometimes cost estimates can be fully or partially based on responsive bids collected from vendors. (Snyder, 2014)

By using management reserve, project organization aims to minimize the effects of errors and uncertainty factors. Management reserve can cover the risks of scope changes, external changes for example strikes or unfavourable weather conditions, estimation errors and changes in cost level. Reserve can be evaluated by using historical data of previous projects and by estimating the unique risk factors of the project. Management reserve should be relative to the accuracy of the estimate and decrease as the cost estimate becomes more accurate. Reserve should cover the costs of minor changes and error in the estimate but for larger changes the new cost estimate should be formulated. (Pelin, 2011)

2.2.2 Project budget

A project budget can be established once an estimate is approved. This involves aggregating the estimated costs of individual activities or construction work packages. (Project Management Institute, 2016) Project budget is used to control the costs and cash flow. The difference between cost estimate and project budget is that cost estimation is a list like evaluation of all the costs of the project. Instead, budget is time phased financial action plan of the project. Usually the project budget concerns only costs. (Pelin, 2011) Costs directly tied to the schedule activities are usually displayed in the form of an S-curve (Snyder, 2014). Incomes can be reported in separate financial budget or in cash flow diagram which represents the difference of budgeted costs and incomes. (Pelin, 2011)

It is important to verify the funding of the project and schedule the incomes so that financial risks are not too high (Pelin, 2011). Total funding and periodic funding requirements are derived from the cost baseline. The cost baseline will include projected expenditures plus anticipated liabilities. Funding often occurs in incremental amounts that are not continuous, and may not be evenly distributed. The total funds required are those included in the cost baseline, plus management reserves if any. (Snyder, 2014) In construction projects the first part payment is often paid after the contract is made. During the project the following part payments are connected to certain degrees of readiness. The last payment is often connected to the handover of the total project and project documents. (Pelin, 2011)

The budget should have the ability to be adjusted and fine-tuned, such that current budget is realistic and in sync with any revised estimates. Further, construction budgets are also used to perform comparisons with subcontractor bids received through the procurement process. Some organizational process assets that influence budgets often include organizational-related policies, procedures, guidelines and tools; historical cost databases; and captured actual costs from each project that the construction organization undertakes, including the reporting methods. (Project Management Institute, 2016)

2.2.3 Cost monitoring and control

Cost control can be divided in three pars: preliminary control while defining the contract, control of cost variations during the project execution and forecasting the final cost of the project. (Ratu, 2015)

Project cost monitoring and control during the production phase includes the status of the project update and track project cost, to manage changes to the cost baseline and to provide a forecast for all remaining cost. The key benefit of cost control is that it provides the means to recognize in a timely manner the variance, from the plan in order to take corrective and preventive actions in order to minimize project cost risk. (Enkovaara and Heikki-Jeskanen, 2008; Project Management Institute, 2016)

The cost monitoring of project is often based on accrual accounting. Actual costs are recorded based on work performed, authorized invoices, progress payments and delivery notes. Tied-up costs can be determined by including uncharged procurements such as remaining sums of contracts and ordered materials. (Enkovaara and Heikki-Jeskanen, 2008)

Cost estimates should be reviewed and refined during the project to reflect additional detail as it becomes available. The accuracy of a project estimate will increase as the project progresses through the project life cycle. (Project Management Institute, 2016; Snyder, 2014) Cost forecasts can be updated during various stages of the project. Actual unit costs can be seen as fixed when the contract of the work is done with the subcontractor, materials are ordered or men are hired to do the work. In the planning phase the quantities are not often very accurate. The cost estimate should always use the most accurate information available and if new quantity information comes available the estimate should be updated. (Seppanen et al., 2005b)

The initial target costs can be used to forecast the cost as long as there is not any changes or any new information available (Seppanen et al., 2005b). The cost forecast of the tasks can be adjusted without any more accurate information if the earlier tasks have exceeded their target costs consistently and over 30 % of the project has been completed (Pekanpalo, 2004).

First new information gathered is agreed unit price or total price for the subcontracts. Also the quantity information can be updated in the bidding process. If the quantities have changed it effects the cost forecast primarily through material costs and secondary through the schedule. Since changed quantities demand different amount of man hours needed to complete the work than initially planned. Both of these must be included in by using the same method as applied when calculating the original target estimate, it is straight forward to calculate adjusted cost forecast. (Seppanen et al., 2005b)

Next step to forecast costs is based on actual recorded production rates and actual quantities measured. After the production has started the actual production rate can be recorded and the man hours needed to complete the task in remaining locations can be estimated based on actuals. Actual production rate thus helps to estimate the labour cost of remaining locations and making the schedule forecasts. Also the actual measured quantities can help forecasting the costs of the task. If quantities in completed locations have constitutively exceeded the planned values it can be assumed that the same quantity overrun is occurring at the rest of the locations too. Information from quantity changes straight from the labourers warns of cost overruns earlier than using information from accounting because it is real time and based on actual measured quantities. (Seppanen et al., 2005b)

Any interruption to work cause either direct or indirect costs. These must be taken into account to cost estimations. Direct cost of waiting time is often compensated subcontractors or workers by paying them their hourly wage for the waiting time. (Seppanen et al., 2005b)

2.3 Earned value management

Earned value management (EVM) is a project management technique. It compares planned resources and used resources to schedule and project scope. (Kim et al., 2003) Separate control and monitoring of cost and schedule is sensitive for bias. It is possible to be within a cost budget, but the project is not proceeding fast enough to meet project schedule. Similarly, it is possible to meet the schedule, but the costs are simultaneously running over budget. (Naderpour and Mofid, 2011) With EVM, such problem is less likely because it combines analysis of costs and schedule variances together to offer managers detailed status of a project (Kim et al., 2003).

The first form of EVM can be found from industrial engineers on the factory floor in the late 1800s. But the term of EVM was introduced first time at 1967 by agencies of the U.S. federal government as an integral part of the cost/schedule control system criteria (C/SCSC). After EVM's introduction in 60's it has been widely and profitably accepted in projects associated with the federal government. To strengthen the status of EMV in private sector, by the end of 1994 U.S. federal government abandoned the idea of C/SCSC and started to use user friendlier earned value management system (EVMS). EVMS is sometimes called earned value project management system (EVPMS). (Fleming and Koppelman, 2005) In its first edition in 1996 Project Management Institute's A Guide to the Project Management Body of Knowledge (PMBOK® Guide) (Snyder, 2014) provided simplified EVM terminology and formulas for private sector. In 2008 Project Management Institute stated that EVM has become the most commonly used method for project performance measurement (Chen and Zhang, 2012).

Kim et al. (2003) stated that EVM has become widespread appliance for different sized project in both public and private sectors. EVM is a useful tool that enables proper monitoring and controlling of time and cost relative to the project's scope. EVM also allows project managers to compare their project's progress to the planned baseline and then assess whether their project will meet budget and schedule goals. (Jrade and Lessard, 2015)

2.3.1 Key parameters of the EVM

EVM uses project parameters to follow and evaluate project progress and performance. Following cumulative key parameters can be seen in Figure 1.

Planned value (PV) or budgeted cost of work scheduled (BCWS) is the authorized cost estimate assigned to activity, work package, or project scheduled. Estimated costs are allocated over the duration of the project and at given moment, planned value defines the physical work that should have been completed. (Snyder, 2014) PV describes the value of work to be earned as a function of physical completion in a given point of time. The graph of cumulative PV is often introduced in a form of an S-curve (Anbari, 2003). Planned Value at a given point of time answers to questions what amount of work is planned to have been completed and what is the cost estimated for the work planned (Fleming and Koppelman, 2005).

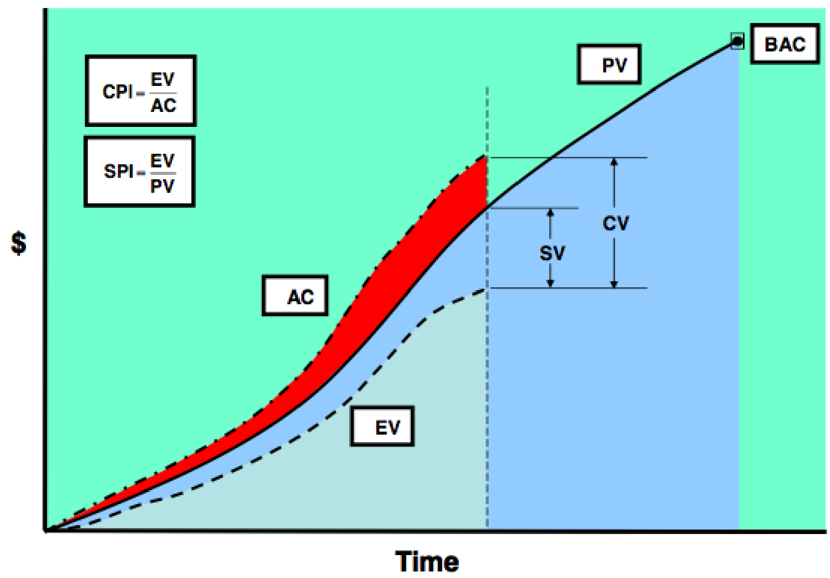

Figure 1: Key parameters of EVM (Anbari, 2003)

Budget at completion (BAC) stands for the total budget estimated of the activity, work package or project. It is planned value's maximum value and the highest and last point in cumulative planned value curve. (Snyder, 2014)

Actual cost (AC) or actual cost of work performed (ACWP) describes the accumulated costs to a given point in time to finish completed activity, work package or project and to earn the value related to the accomplishment (Snyder, 2014). At any point of time the actual cost answers the question what have our costs been (Fleming and Koppelman, 2005).

Earned value (EV) or budgeted cost of work performed (BCWP) is the cumulative earned value of the work completed up to a given point in time. It represents the resources budgeted for completing the work that was actually physically completed. To obtain earned value for a component, tasks total budget is multiplied by its completed proportion. (Snyder, 2014) EV answers to questions what work has been accomplished and what was the cost estimated for the completed work (Fleming and Koppelman, 2005).

2.3.2 EVM measures

After the key parameter are defined the progress performance of the project can be determined and analysed by calculating variances and indices called EVM measures and analyzing them.

Cost performance of the project can be determined by comparing the earned value to actual costs of the activity, work package or project. Schedule performance can then be determined by comparing earned value to planned value. Comparison can be carried out by calculating the corresponding variances, the variance percentages or performance indices. Variances can also be determined from the graph as shown in Figure 1. (Anbari, 2003)

The following formulas can be used to calculate variances and indices based on cumulative planned value, earned value and actual cost data.

Cost variance (CV) is a measure of cost performance and it represents the budget deficit or surplus at a given point of time. CV is measured as the deviation of AC from EV and can be calculated from the formula CV = EV - AC. when the activity, work package or project is finished cost variance presents the difference between BAC and the actual amount spent. (Snyder, 2014)

Project's schedule performance can be measured by calculating schedule variance (SV). Schedule variance is presented as EV's deviation from PV. Formula for calculating the schedule variance for the activity, work package or project is SV= EV- PV. Calculated schedule variance is the measure for how much the project is ahead or behind from the planned schedule. (Snyder, 2014) In this form the schedule variance is presented in monetary units. Using this formula for schedule variance is widely discussed and substitutive formulas have been presented because schedule variance presented in monetary units is not the most informative and clear way of presenting the schedule performance.

In variance formulas presented before, 0 indicates that production proceeds as planned and performance is on target. Variance values bigger than 0 indicates higher performance than expected and then lower values poorer performance than expected. (Anbari, 2003; Snyder, 2014)

Spend rate or burn rate can be expressed as cost variance per time. Similarly, the planned accomplishment rate, planned value rate or the PV rate can be expressed as the average planned value per time. PV rate is defined as the budget at completion (BAC) divided by the schedule at completion (SAC). As a formula PV rate = BAC / SAC.

With help of PV rate, monetary schedule variance can be translated into time units by dividing schedule variance by the PV rate. The result is the schedule variance in time units called the time variance (TV). Time variance is presented as formula TV = SV / PV rate. (Anbari, 2003) This expression eases the understanding of schedule variance, but does not solve the problem of SV approaching the ideal value towards the end of the project even if the project is late.

Time variance measurement can also be presented graphically on the chart. This can be established by drawing a horizontal line from the earned value curve at the status date to the planned value curve and reading the time distance on the horizontal axis (Anbari, 2003).

The cost variance percent (CV% or CVP) describes the budgetary coherence of actual cost of work completed. Formula for CVP is presented as CVP=CV/EV. Similarly schedule variance percent (SV% or SVP) measures the conformance of actual progress to the planned schedule. Formula for SVP is determined as SVP = SV/PV. (Anbari, 2003)

Anbari (2003) considered if using earned value rather than planned value in the nominator of schedule variance formula is more appropriate. He defined the schedule variance percent based on the earned value (SVev% or SVPev) by using formula SVPev = SV/EV. SVPev is consistent with the formula for CVP. The difference between SVp and SVPev is that SVPev identifies that measured schedule variance occurred while accomplishing EV. Therefore, it may indicate the project schedule status better than SVP calculated with PV. (Anbari, 2003)

In addition to variances, following indices are used to evaluate the performance of the project. The cost performance index (CPI) measures the cost efficiency of performed work. CPI is calculated as a ratio between earned value and actual cost. This is be expressed as formula CPI = EV / AC. This is often considered as the most critical metric of EVM. Similarly schedule performance index (SPI) measures schedule efficiency. SPI is expressed as ratio between earned value and planned value. SPI = EV/PV. SPI indicates how timely efficiently the work has been performed. (Anbari, 2003)

If the result of CPI or SPI is 1 the projects performance is as efficient as expected. Bigger performance index values indicate excellent and highly efficient performance and similarly smaller values indicate inefficient performance. The inverse formulas of performance indices presented above have also been used. For project manager the graphs of performance indices over project's duration can provide valuable information about trends in project performance and impacts of corrective actions taken. (Anbari, 2003)

Critical ratio (CR) or cost schedule index (CSI) is the product of CPI and SPI together. CR indicates the overall project health. Critical ratio is calculated with following formula CR = CPI x SPI. If the result of critical ratio is 1 the projects overall performance is on target. This means that either both CPI and SPI are on target or close to target or if either one of the indices is suggesting poor performance, the other one must indicate good performance. This means that some trade offs are allowed to reach the goal of the project. If the result of critical ratio is more than 1 the overall project performance is excellent. Excellent performance can be a result of both SPI and CPI being over the targeted, or if other is resulting poor performance the other must be resulting excellent performance. If critical ratio results less than 1 it indicates that the overall performance is poor. As previously likewise this can be a result of both CPI and SPI resulting poor performance or if other is resulting good performance the other must be resulting extremely low performance. Critical ratio over time can be expressed as graph and be used as indicator of trends and impacts of corrective actions. Graphs of CPI, SPI and CR can offer useful information for the project manager and be very effective in project reviews. (Anbari, 2003)

2.3.3 Advantages and disadvantages of EVM

According to the research of Kim et al. (2003) earned value management is deeply accepted as project management tool among project managers. According to their research 82 % of project managers who have used or are currently using earned value management tool accepted the methodology. Also in five of the six cases the senior managers and project managers are strongly accepting EVM as project management method. Hight acceptance was recorded in both public and private sector and it implies that EVM can easily be applied profitably in both sectors.

The main advantages of using EVM are integration of cost, progress and time management, clearer insight of the project scope (Valle and Soares, 2006), early warnings on problems and predictability of project deviations (Naderpour and Mofid, 2011; Valle and Soares, 2006). EVM also reduces time to identify and understand problems and find suitable solutions. It also works as a supporting material in negotiations and decision-making. Earned value management has also been noted to motivate employees to implement the project control process (Valle and Soares, 2006).

Empirical studies revealed many factors that may disrupt the implementation of EVM. The possible factors found are high cost, complicated and demanding paper work, lack of understanding the theory of EVM (Brandon and Daniel, 1998; Kim et al., 2003), lack of trust and understanding between project managers, project consulting and government, pressure to give only positive reports (Fleming and Koppelman, 2005; Kim et al., 2003). Fixed price contracts make use of EVM less atractive to client and lack of cost and schedule integrated data (Chen and Zhang, 2012). Factors that can slow down the implementation of EVM are according to De Marco and Narbaev (2013) the need of detailed planning and scheduling before the project starts, reliable and honest reporting and difficulties in measuring actual physical progress of construction activities.

The difficulty of determining the percentage of completion for some tasks is seen as a practical problem of EVM (Brandon and Daniel, 1998; Czernigowska, 2008; De Marco and Narbaev, 2013). It is straight forward to determine the state of completion for tasks that have measurable results. But the progress of more complex tasks or tasks that do not have tangible or measurable results has to be estimated. Couple of strategies to tackle this problem has been presented. Task can be assumed to be 0% complete until it is done, then it marked 100% complete. This is safe and pessimistic way, but it undervalues only partially completed tasks. Another way to estimate these tasks is applying a fixed percentage at the beginning of the task and keeping it until the task ends, then it will be marked 100% complete. The third way to estimate tasks with no measurable result is so called "eyeball" assessment. That means subjective judgement, since it is better to make a rough estimate of a progress than not to estimate the progress at all. All the approaches presented do not cause error to the overall picture of the project progress if applied at low levels of work breakdown structure. (Czernigowska, 2008)

Czernigowska (2008) identified that it is crucial to evaluate what are the costs included in earned value analysis. There are lags between completed work and expenditure since labour is paid biweekly or monthly and terms of payment for subcontractors and material deliveries can vary. Assessing actual costs based on invoices can be problematic since payment delays and invoices can include costs caused by other tasks too. It is important to separate overhead costs from the tasks specific costs in actual cost comparison to budgeted. It is also important to note that contractor's BAC, PV, EV and AC do not contain any profit or contingencies since EVM follows costs not revenues (Czernigowska, 2008; Howes, 2000).

The nature of schedule variance and schedule performance index have been criticized by Corovic (2006), Lipke (2003) and Henderson (2004, 2007). First problem is that the SV is measured in monetary units not in time unit. This may be challenging to understand and it causes misunderstandings. This problem was later fixed by creating the metric of Time Variance (TV) calculated as a ratio between schedule variance and planned value rate. Second problem is that SV = 0 or SPI = 1 indicates that a task either finished or progressing as planned. Without any additional information project manager can not know which one is the real situation. The third note is that when approaching the end of the project the schedule variance always gets closer to 0 resulting perfect performance also when the project has fallen behind the schedule. Similarly, SPI always gets closer to 1 when approaching the end of the project, indicating a 100% schedule efficiency in the end of the project even when the project is completed late. As a result of this kind of behaviour, at some point in time the SV and SPI start becoming unreliable and better indicators should be found to describe the schedule performance. This happens usually after the two thirds of the project are completed (Lipke, 2003). Because of the nature of SV and SPI, after the scheduled end of the project, planned value remains constant at BAC while the earned value is supposed to grow until it reaches the BAC. For example if project is scheduled to be completed in 5 months and EV is 80 % after five months, the project is obviously 20 % behind the plan. After five months the project is continued to be finished but for some reason it is not proceeding during the next two months, the SPI stays the same. And in the real end of the project EV is equal to PV which according to EVM means that the project has finished on time even though it finished several months later than planned. (Corovic, 2006)

The weakness described above is noticed by many authors including Fleming and Koppelman (2005), Henderson (2004), Vandevoorde and Vanhoucke (2006) and Czernigowska (2008) and it is nowadays included in PMI Practice Standard of EVM (Corovic, 2006). Most of the authors mentioned before argue that the forecasts based on EVM schedule variances are unreliable and recommend that EVM, schedule performance indices should be used just as alarm signal, not schedule performance analyzing tool. According to Corovic (2006) some researchers still consider SPI to be useful and reliable in first two thirds of the project and unreliable only over the final third of the project. Corovic (2006) states that the schedule indicators of EVM are unreliable and defective also in the early stages of the project for the projects in which a cumulative cost curve is not linear. Valle and Soares (2006) suggested to change the name of SPI to Progress Performance Index because it measures progress, not time.

Because of the problematic schedule variance and schedule performance index the use and research efforts on EVM have mainly focused on cost. The problems in schedule indicators are widely known and understood and because of that they are not trusted at the same level as cost indicators are. This has caused the disconnection between cost and schedule management on the project status and performance monitoring. EVM practioners have desired the ability to analyze and forecats both cost and schedule from EVM data reliably. Several approaches to analyze and forecast schedule performance based on EVM data have been proposed and studien over the years. (Henderson, 2007) Still none of techniques presented by Anbari (2003) have been proven to be accurate enough for both early and late finishing projects (Henderson, 2007). As a solution to weaknesses described above the earned schedule (ES) metric has been developed (Corovic, 2006; Lipke, 2003).

2.3.4 Earned schedule ES

Earned schedule was developed because the schedule indicators of EVM initially seems to be establishing a trend but when getting closer to the end of project start moving towards their end result, zero variance and an index value equal to one. This behaviour of SV and SPI have noted to occur without fail for every project finishing no matter how late. Some authors stated that SV and SPI are still reliable over first two thirds of the project and lose their reliability only over the last third (Corovic, 2006; Rubio et al., 2015). The unreliability of the indicators in the end phase itself is problematic but as problematic is the grey area where the project manager cannot be sure should the indicator be trusted or not (Lipke, 2003).

Earned schedule theory uses the same data as earned value. The main difference is that instead of comparing costs to determine schedule variance earned schedule uses time. Earned schedule identifies the point in time at which the amount of earned value currently completed should have been accomplished. (Henderson, 2007; Lipke, 2003). More precisely earned schedule can be calculated as illustrated in Figure 2. The current cumulative value of earned schedule is the point in time in which the current value of earned value was planned to be completed. (Henderson, 2007).

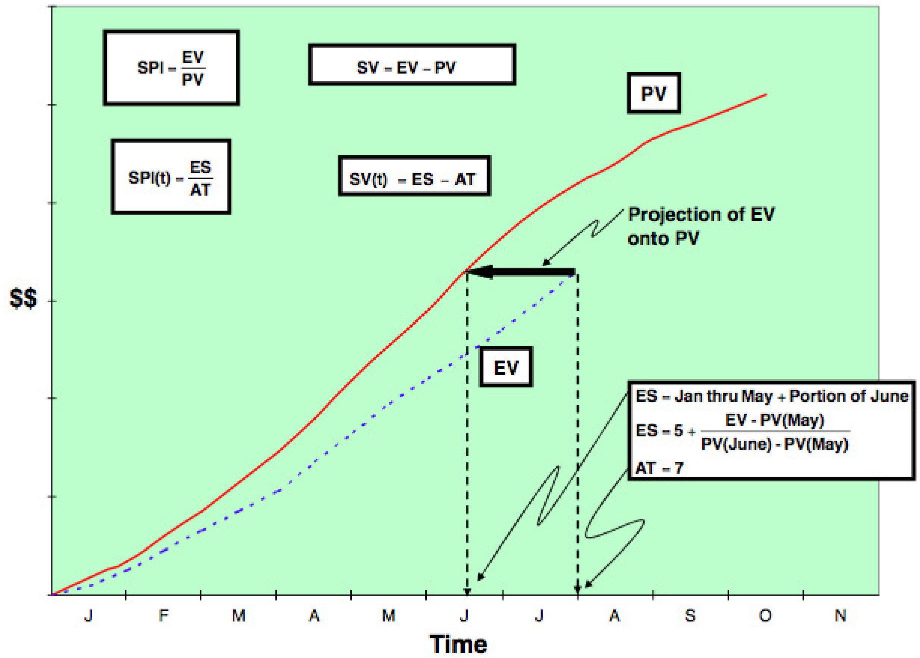

Figure 2: Earned Schedule (Henderson, 2007)

Earned schedule theory presented indicators of schedule performance analogous to cost indicators. Schedule variance in time units is calculated as difference between earned schedule and actual time (AT) used to achieve the state of completion. Formula for schedule variance according to earned schedule theory is presented as SV(t) =ES - AT. Similarly schedule performance index is calculated as ratio between earned schedule and actual time SPI(t) = ES/AT. (Henderson, 2007)

Similarly to CV and SV calculated according earned value theory positive SV(t) value indicates that project is proceedinf adhead of schedule and negative that it has fallen behind the schedule. Similarly SPI(t) is totally analogous to CPI and SPI since result greater than 1 indicates better performance than expected and less than 1 lower performance than expected. These schedule indicators provided by earned schedule theory behave correctly over the entire life of the project. (Lipke, 2003)

The correctivenes of earned schedule indicators have proved by Henderson (2007). He used EVM data from various completed projects of information technology and verified that of ES measures functioned as described in seminal paper of Lipke (2003). The behaviour of earned schedule variance and indices have been researched and verified to be applicable by using real data from various types of projects (Henderson, 2007; Rubio et al., 2015).

2.3.5 Implementing earned value on any project

The following steps needs to be performed to implement earned value management system to any project. Employing earned value performance measurement should not require any additional planning to that necessary to implement any project.

Earned value monitors the physical completion of work and budgeted cost for the completed work. Such monitoring should take place from as early as possible until all the physical work has been completed. Scope creep would negate the possibility of accurately measuring project performance along the way. (Fleming and Koppelman, 2005) Therefore to the effective management of any project the scope management is vital. Unless the full scope is properly defined and then managed throughout the duration of the project, the possibility to meet the objectives of the project will be severely compromised. (Fleming and Koppelman, 2005; Lukas, 2012)

Fully implemented earned value requires segmenting project scope into controllable parts using a work breakdown structure (WBS) (Fleming and Koppelman, 2005; Lukas, 2012; Project Management Institute, 2011). WBS includes all work tasks for the project and defines the scope of project. The WBS is a product oriented hierarchical system that describes all the major segments of the project and is used to specify all products. The WBS is used to specify all of the assumed work. Each level of WBS provides a progressively more detailed description of the work to be accomplished. At the lowest selected levels of specified WBS elements will be placed control account plans (CAPs) which are the points at which earned value performance and management control will take place for the project. All project management CAPs must contain four elements in order to be viable: scope of work for the CAP, specified time frame for performance; an authorized budget; and a specific individual or organization to be held accountable for performance of each CAP. (Fleming and Koppelman, 2005)

After the work breakdown structure is defined the next step is to schedule the project using any of the available scheduling systems. The schedule of the project portrays the work scope approved, since all the tasks included in the work scope are planned and placed into a schedule. At scheduling phase every CAP is given its time frame. (Fleming and Koppelman, 2005) Planned value is constituted of scheduled work tasks together with their authorized budgets. As the project is progressing the completed portions together with their budgets determine the earned value. (Fleming and Koppelman, 2005; Project Management Institute, 2011) Both planned value and the completed earned value are tracked from the master schedule of the project. Planning and measuring the state of completion must use the same measurement metric to make the comparison possible. Project master schedule is vital to earned value because the comparison can't be done without the baseline schedule. (Fleming and Koppelman, 2005)

After the work to be done is defined and scheduled properly the next step is to estimate the resources needed to complete the scope in planned schedule. Costs for each CAP are estimated based on the best information available at the time. As a result are the authorized budget for every CAP. (Lukas, 2012) These individual authorized budget should not include any risk or management reserves. Authorized budgets must be able to be achieved to have feasible planned value. (Fleming and Koppelman, 2005)

Next step implementing earned value analysis is to determine the metrics to convert planned value into earned value. This means that schedule must be expressed in measurable metrics that authorized work and completion of authorized work can be quantified and measured. Physical performance of tasks is measured using weighted values or specific milestones. Various methods have been introduced and tested, but the most commonly used methods use some kind of discrete measurements. Specific milestones represents the points in time with assigned values. When the milestone is fully completed the assigned budget is earned. (Fleming and Koppelman, 2005)

Earned value methodology requires the integrated baseline which basicly means that the defined work scope includes both schedule and authorized budget. This integration must take place within each of the WBS elements. (Fleming and Koppelman, 2005; Project Management Institute, 2011) Each CAP should have its time frame and authorized budget. Planned value is formed as a sum of CAPs. Earned value performance measurement will actually take place within each of the CAPs. Total project performance is simply sum of the CAPs, placed at any level of the WBS. (Fleming and Koppelman, 2005)

To be able to analyse the project with EVM tools, the actual costs must be recorded and compared to the authorized budgets (Lukas, 2012). Planned value represents the work scheduled and the budgeted cost of it. Budgeted cost will be converted into earned work at the same budget to represent the earned value. Earned value must be comparable to actual cost to make the cost performance analysis possible. Thus recording the actual costs by CAP level is absolute requirement for efficient EVM analysis. (Fleming and Koppelman, 2005; Project Management Institute, 2011)

While the project is progressing the cost and schedule must be monitored and compared against the baseline from the beginning to the end of the project (Lukas, 2012). If the projects progress is deviating from the baseline especially if the deviation is more than accepted variances the attention needs to be paid to possible reasons. If variances and indices indicate that a task is falling behind the criticality of the task should be assessed. If the late task is on the critical path or on nearly critical path corrective actions needs to be planned and taken. The cost variances and indices must also be taken into account. If task is spending more money than it is receiving value the situation needs to be evaluated and corrective actions taken. (Fleming and Koppelman, 2005)

Forecasts offered by the EVM theory are seen as one of the most beneficial aspect of earned value project management. Based on actual costs and realised schedule performance the forecasts on total costs of the task and total duration can be determined. These forecasts can be calculated throughout the whole project to estimate the final result. (Fleming and Koppelman, 2005)

The project performance baseline needs to be updated every time the project scope changes or any other changes come out that have an affect on schedule or costs of the project. There is no use in following the old baseline that does not take any changes into account. Maintaining baseline that reflects the scope throughout the project can be as challenging as defining the original baseline as the project starts. (Fleming and Koppelman, 2005; Lukas, 2012)

2.3.6 Applications of EVM in construction projects

According to Chen and Zhang (2012) when implementing EVM on new country or busines area, earned value management method should be modified to fit the existing project management and control methodologies. When the EVM is introduced applicable information presentation model suitable for domestic market or business area should be developed because EVM outputs are highly depending on the quality and type of cost and schedule data. (Chen and Zhang, 2012)

Earned value management is widely accepted in construction projects all over the world since the defence departments of Australia, Canada and the U.S. joined and created together the International Performance Management Council to speed up collective development of the EVM methodology in 1995. Australia and Canada have already took up EVM by establishing the EV criteria and industry standards similar to U.S.standard both in defence and private sectors. Japan joined the EVM community through its Ministry of Construction. De Marco and Narbaev (2013) wrote a paper about application of EVM in European construction Industry. They stated that EVM is not as widely accepted in Europe as it is in the U.S. In Europe the U.K. and Sweden experienced the largest amount of reported applications of EVM methodology in 2013 (De Marco and Narbaev, 2013).

Recorded application of EVM in consructipn projects are found from various different project types. De Marco and Narbaev (2013) had a case study of an Italian renovation project of an industrial facility. Alvarado et al. (2005) wrote a paper about implementing EVM in projects of General Services Administration (GSA) in U.S. Valle and Soares (2006) researched implementation of EVM in indoor amusement park called Monica Park in Rio De Janeiro in Brazil. Marzouk and Hisham (2014) presented the application of Earned value management used in bridge project on Abo-Diab bridge, located in Al-Buhayrah governorate, Egypt. It can be concluded that EVM can be applied in various different construction projects from bridges to amusement parks including renovation projects too. EVM is also applicable in private and public sector projects as well.

Steps described in 2.3.5 apply on implementing the EVM in construction projects too. As Fleming and Koppelman (2005) summarized, the steps to effectively build the planned value graph includes work scope decomposition to task level and creation of work breakdown structure (WBS), assignations or responsibilities, development of time phased cost estimation for each WBS item, maintain of planned value integrity. Performance measurement and analysis is composed of resource usage recording during the project's life, objective measures of the actual physical work progress, cost and schedule analyses and forecasts, reported performance problems and corrective actions.

Research paper offer varying steps to implement EVM, but the main idea is the same as the implementation process described by Fleming and Koppelman (2005). At first the total duration of the project and contract amount should be determined. (Alvarado et al., 2005). In the case study of De Marco and Narbaev (2013) the scope of work was firstly decomposed to detailed level enough to measure the progress. According to Valle and Soares (2006) the WBS is important to be determined to suit the scope to offer applicable way to measure performance and control the accounting. The lowest levels of WBS must have clear responsibilities and the criteria on how the progress is measured.

After the WBS is defined the planned value curve to be used needs to be determined. Project specific curves should always be used if available. Otherwise standard curves based on historical data and regression analysis can be used with care. (Alvarado et al., 2005) As Fleming and Koppelman (2005) instructed the planned value curves should be developed before the project starts. According to Kim et al. (2015) cumulative planned value can be calculated as sum of the planned construction cost according to the construction schedule. But in many cases as in the case of Alvarado et al. (2005), planned value curves cannot be determined accurately for the project so standard planned value curve was required. But in their case the Public Buildings Service (PBS) of GSA already had all the data required to perform earned value analysis since they have been using a form called "Form 184" that contains information about the total contract amount to date, change orders requested, the value of the work completed to date and the value of work completed under the change orders. As Form 184s are submitted monthly, the earned value curve can be drawn. The form has been used for more than 20 years and thus offered loads of historical data. Using historical data available the team developed standard normalized planned value curves resembling an s-curve for different types of projects.

Next step is to decide the criteria to determine projects schedule performance (Alvarado et al., 2005). De Marco and Narbaev (2013) chose simple technique for measuring progress called the on/off approach. Next they defined the weighted summation of individual elements from lowest to the top level of the WBS to compute the total state of completion of the project. Final step is to obtain data about earned value from project regularly and compare it against planned value (Alvarado et al., 2005). Based on monthly presented performance monitoring reports, the project management team is able to calculate the EV variables and estimates for costs and schedule. (De Marco and Narbaev, 2013)

Kim et al. (2003) found out that most of the EVM users have implemented at some level an automated computer system to support EVM calculations. According to Chen and Zhang (2012) several widely used project management softwares such as Microsoft Project and Project Server have included the analysis processes of EMV. Also Chou et al. (2010) concluded that project progress information must be visually presented and automatically formulated for efficient management process. They created a prototype system that visualizes the project progress as EVM parameter graphs to Web to offer project manager access on real time information. The prototype offers project managers a simple and real-time visual tool for tracking and updating time and cost based data. This allows them to update newest information to the system and input scope and quality notes during the projects construction.

To create more accurate planned value graphs and measures of earned value Marzouk and Hisham (2014) presented the application of Earned value management cost and schedule management combined to Bridge Information Modeling (BrIM). Application performed in an automated manner to perform cost estimates and project baseline. Also the performance measurement with earned value metrics was performed automatically throughout the project. The cost estimation presented in the paper consisted two modules. The first module was approximate estimate. The first module got its quantity information of elements straight from the bridge information model. The first module calculated estimated costs by multiplying the quantities with equivalent unit prices found from the default values of the module. Unit prices could also been defined by the user in user interface of the module. The first module creates a excel sheet including cost estimate for each element. Second module integrated construction knowledge with quantities to obtain more detailed estimate. Integrated construction knowledge included productivity knowledge, different material costs and labors and equipment rates. These values are either default values or they can be set by the user in element level or project level. After the values are set the second module creates excel sheet including material costs, labor cost and equipment cost of each element. The paper also presented BrIM Performance Measurement Module. This module worked in task level and element level considering defined control accounts. On task level the performance measurement module used Tekla Structure Software's Task Manager module to derive actual and planned values. Based on this data module performed earned value calculations. The module created excel sheet including task information, earned value parameters and statuses of budget and schedule. On the element level user could insert the planned and actual values for each element separately. Based on the data inserted on elements the module performs earned value calculations and determines the cost and schedule statuses. (Marzouk and Hisham, 2014)

Another example on integrating BIM with EVM was presented by Jrade and

Lessard (2015). They created an integrated time and cost management system (ITCMS). ITCMS is composed of four modules; vizualization module that refers to 3D modelling module, cost and time estimation module, scheduling module and EVM module. In practise every 3D-model component is given cost estimate and installation schedule. As a result the 5D model is created that integratesthe time and cost data for the building and its components. During the constructuin the EVM module of ITCMS is used to evaluate project performance based on physical completion of the building components. Change managements is established by updating the 5D model, by updating 3D model, budget and schedule it is composed of. Projects progressis measured as a state of completion of each component of the model. EVM curves and ratios are updated automatically based on completion data. They used multiple softwares such as MS Project,Microsoft Excel, Autodesk's Revit, Quantity Takeoff, and Navisworks to create the information and to combine it. Jrade and Lessard (2015) identified multiple benefits including the ability to include installation time and cost values to each of the building model component properties during the design phase; facilitated estimating process with automated outputs; creation of a time and cost baseline that serves as a reference for EVM performance reporting and visual tool better comprehension among the project team. They concluded that budget and schedule management platform, coupled with BIM tools and processes, will inevitably improve construction productivity, constructibility, and overall performance.

To ease the tracking of states of completion Ghanem and AbdelRazig (2006) presented a application of Radio Frequency Identification (RFID) tag. In their method construction materials were tracked and identified with tags. The information from tags were scanned and the track information was imported in database. As a solution to same problem Turkan et al. (2012) created a system which utilizes automated 4D object recognition system. They linked the recognition system with project's control accounts to produce more accurate and real time earned value data. They performed the linking manually by combining the information produced by the automated object recognition system with projects control accounts and object quantities on Excel. Two different construction sites were used test the system of automated tracking of volumetric work. Some tasks can not be tracked automatically because the system can not recognise linear objects or changes of surface's stage. They resulted reasonably accurate earned value analysis of the structural erection progress of a project They noted that it is necessary to ensure that all the objects that are needed to be tracked are present in the scans. As their conclusion they stated that automated tracking of objects can improve the accuracy of progress tracking and support other project systems for example billing.

De Marco and Narbaev (2013) saw three reasons that might have an influence on usage diffusion of EVM in Europe. First reason might be that there is not enough recorded applications in construction projects in Europe and the sources of reported best practises and European case studies are limited. Another possible reason is that there are not many research groups focused on researching the EVM theory, spreading it and providing its benefits to users.

Third reason could be that there is no EVM criteria and industry standard established in Europe as in U.S., Canada and Australia. Valle and Soares (2006) noted that main problems implementing EVM are the needed cultural change and the negative resistance of people due to the effort of implementing EVM. They noted that EVM is very sensitive for scope changes.

The case study of De Marco and Narbaev (2013) proved that schedule forecasts based on earned schedule variances and indices give better estimate of the total duration of the project at completion. The paper concluded that the advantages of EVM should be approved among construction professionals in Europe to assist adoption and utilization of the EVM methodology. They proved that EVM is applicable to any size and complexity of facility construction projects. They also proved EVM's ability to integrate cost, schedule and scope management in single management tool and predict performance. According to Valle and Soares (2006) the EVM database and reporting system provided easy coherence analysis for data. EVM allowed scope change management to keep the final budget of the project within check by providing alternatives to decide in what activities to reduce scope or reduce specifications/performance to save money in order to fit cost overruns in other activities.

2.3.7 Adapting EVM to location-based management system

Most of the applications of EVM presented previously were applying traditional planning and scheduling methods like critical path method (CPM), PERT or Gantt chart. Because location-based management system is more widely adapted to use in Finland as CPMs (Olivieri et al., 2016), a closer look to adaptation of EVM to LBMS needs to be taken.

Seppanen et al. (2005b) applied earned value management to location-based management system (LBMS). They stated that location-based cost control method sets a demand for location-based quantities as a starting data. If each quantity item can be given price of a unit and labour consumption, it is possible to calculate man hours needed to complete the work in given location and the cost estimate for the work. Thus target costs for each task in each location can be calculated and the timing of the costs determined automatically. This is possible because cost estimate quantities are directly scheduled during the scheduling process of the project. (Seppanen et al., 2005b)

Costs of the quantity items are linked to tasks but overhead costs are not imported to schedule tasks. Therefore alternative method for estimating overhead costs need to be developed. Seppanen et al. (2005b) suggested calculating unit cost for each overhead cost item. The unit cost of overheads are then multiplied with the duration of either the whole project or the tasks affecting the overhead cost.

The payment plans vary between subcontractors, material purchases and direct labour. Usually timing of payments can be divided into two payment types which are time-based or milestone-based payments. Time-based payments are commonly paid monthly, bimonthly or sometimes biweekly, for the work in progress. Milestone-based payments are paid when the specified milestone is met. Milestones can be defined to be certain completion rates for the whole task or completion of certain locations. Traditional critical path method contract administration systems are activity-based and progress payments are based on percentage complete of the entire activity. There is no reference to the amounts of work in specific locations. In Finland the alternative common is to link the payments to completion of locations. (Seppanen et al., 2005b)

Seppanen et al. (2005b) stated that when quantities, start and end dates and production rates in every location are known the estimated payments can be calculated not matter which one of the payment types is preferred. Because the dates and amounts of payments are determined by the schedule, it is possible to assume the planned value curve by taking into account the payment delays.

According to (Seppanen et al., 2005b) on site management on of the biggest problems is the poor performance of subcontractors. Particularly steering them to work on and finalize one location at a time and moving the the next progressively. The reason for working in multiple locations at a time is the use of traditional percentage completed of total activity payment type. Management of payments by location instead of completion rates drives to complete one location at a time and therefore supports lean construction. Best solution is to pay subcontractor based on allocated completed locations. This method steers the subcontractor to work progressively since work done out of the determined sequence is not recognized as done and therefore not paid.

2.4 Key take-aways from literature to this study

Based on literature review earned value management is widely and successfully applied in construction projects in U.S., Canada, Australia and Japan. In Europe EVM is not as widely accepted as a project control tool, but some recorded applications prove the effectiveness of the methodology in construction projects. It can be concluded that based on literature EVM can be successfully applied in construction sector as well as any other sector. EVM has proved to provide vital information for the project managers since it combines the scope, cost and schedule monitoring and controlling together.

As an answer to research question "How EVM can be applied?" the key steps on how to implement EVM on any project can be summarized based on practise standard by Project Management Institute (2011) and the recorded applications from construction field. Briefly The steps to implement EVM are: defining the scope of project, decomposition of work and creation of WBS, scheduling the project, estimating costs, creating project baseline and monitoring accumulating costs and physical state of completion.

The basics of schedule and cost management was reviewed at first. According to literature the basic cost and schedule planning and control covers all the planning and information gathering needed to implement earned value management to any project. Thus applying EVM should not require any additional planning or monitoring if the project management and control are already on a good level.

As an aswer to research question "how EVM key parameters can be automatically determined?" Kim et al. (2003) and Chou et al. (2010) stated that the best way to apply EVM is trough automated computer system that makes the EVM calculations and plots the graphs automatically based on imported cost, schedule and completion data. Since all the needed information is already gathered during normal project management processes, the data should be able to be automatically transformed into EVM graphs. Chou et al. (2010) presented a system they created to automate the data collection and EVM calculations.

Some advanced technologies were presented to automatically offer more accurate EVM calculations. The integration of cost and schedule data to 3D model was researched by Marzouk and Hisham (2014) and Jrade and Lessard (2015). For more accurate schedule moitoring Ghanem and AbdelRazig (2006) offered a solution based on RDIF technology and Turkan et al. (2012) based on automated 4D object recognition system. Both systems aim to monitor the physical progress continuously so that the accuracy of progress data will increase and more updated EV values can be drawn.

The main improvement of EVM on cost and schedule monitoring is its ability to integrate cost, schedule and scope management in single management tool and predict performance. It was also reported that EVM offers easy analysis tool for performance and cost data.

3 Empirical research

This chapter represents the current way of managing projects at the residential construction unit of NCC Building Finland. The subjects covered in this chapter are production planning and control, including schedule planning and schedule control, cost management and the project's progress monitoring and applications of EVM.

3.1 Production planning

Projects schedule planning is started by forming the master schedule for the project. Master schedule includes all the tasks of the project including heating, plumbing, ventilation and electrical installation tasks. This master schedule with all its tasks is not presented as it is but certain views are gathered and elaborated as the project progresses. Master schedule is formed before the construction phase starts. It is the basic plan of project implementation and schedule control and defines the schedule targets of the project.

The first view of master schedule is the general schedule which presents the key tasks of the project. General schedule can present the master schedule tasks in higher level for example using summarized tasks. General view acts as a informational tool for project stakeholders and is the binding document for contracting parties.

As the project progresses new views are formed and expanded. For example construction stage views, task schedules and weekly schedules. More accurate level schedules are always based on general schedule and make sure that the targets of general schedule can be met. The views to be generated are defined construction site specifically in the project plan of the project.

3.1.1 Schedule planning

Schedules are planned by using Vico Schedule Planner sofware by Trimble. The schedule is based on the bill of quantities imported from TCM-system. If the bill of quantities is based on location breakdown structure (LBS), the same LBS is created to Vico Schedule planner file. The BoQ is often bought from another company and in that case the demand of LBS must be specified in the call for bid. For some concept projects the BoQ is calculated by own employees, but most often it is bought from outside. Quite often the BoQ is not available on location level, and the quantities by location must be assumed. If there is no LBS in BoQ the planning starts with creating LBS. LBS should be hierarchical and take into account the production sequence of the project. Normally the locations are organized by the building, staircase and floor. Usually floor level is the lowest level used, but sometimes the schedule is planned on apartment level.

Schedule tasks are composed from one or multiple cost estimate control accounts to ease the monitoring of project progress. The tasks should be composed of quantity items that are included in same purchase package. This eases the monitoring of the progress of sub contractors. Consumption rates, performance and resources of the schedule task are defined as the task is created. Consumption rates are estimated based on labour consumptions recorded by RATU for the optimal amount of resources. Sometimes the consumption rates are estimated based on own knowledge or guesses. Schedule planning manual of residential unit written in 2009 recommends to use the same control account codes for the schedule tasks to ease the cost-schedule control, but in practise there is no general way for coding or naming tasks. Any specific templates for schedules are not used.

As schedule planning proceeds the schedule should be examined and edited in location-time graph to observe clashes between tasks. The tasks are synchronized with each other so that clashes are avoided. Enough lag after concreting tasks need to be added to make sure the curing times can be met. Time buffer of two weeks is recommended to be used between tasks to reduce the risk of clashes.

3.1.2 Schedule control

As the construction phase starts the project should have the master schedule and the general schedule view. Detailed scheduling and monitoring is based on general schedule. During the construction phase all schedules are monitored through actual quantities and performance. Detected deviations are reported and production is steered back to original schedule by proper control actions.

Actualization of planned work is ensured weekly. Monitoring is based on actual quantities and performance of the tasks. Logged actuals of tasks are illustrated in the control chart and in flow line view as dash line. Updated control chart is kept on visible place in the site office and presented to subcontractors at subcontractor meetings. Schedule monitoring is site engineer's responsibility. Site engineers estimate the completed quantities once a week. For most of the tasks the state of completion is determined by checking how many of the apartments of certain floor are completed of the total. For tasks like foundation work or earth works the state of completion is difficult to estimate accurately. It turned out in the interviews of site engineers that there is two common ways to mark the start and end dates of tasks in locations. Some try to determine the exact start dates for tasks by estimating it based on estimated performance or by asking exact dates from site foremen. Some mark the start and end dates on weekly basis so that if they notice some task has started after the last update to control chart they mark its start day to the day they are updating the control chart and similarly if they notice a task has ended after the last update they mark its end date to the day they update the chart.

Control actions are taken if there is a detected deviation from the original plan. Possible control actions are: changing the composition of the working group, changing the shift length with over time work, changing the scope of work, making the task discontinuous, changing the working sequence or method and adding prefabrication. According to interviews of construction managers and site engineers the actual progress and forecast diagrams are not used as effectively as they could. Some site engineers follow actual and forecast lines, but mostly the only tool used to monitor the progress is the control chart view.

Control chart is used to communicate the progress to project organization, sub contractors and clients. According to interviewed site engineers the site foremen don't use actively the information offered by control chart or actual progress and forecast lines formulated by Vico schedule planner. Most of the site engineers feel that the control chart is not used as effectively as it could and that they follow the production mostly for their own advantage. Even tough site engineers feel that the information they gather is not actively used by the other parts of organization they see schedule monitoring as important for themselves.

Weekly monitoring is continuous over the whole life cycle of the construction phase. All of the site engineers interviewed monitor the production over the whole project, but they feel that the early phases are hard to monitor because there is no easy way to measure for example excavation or mining. While gathering data for EVM application it was noted that many of the previous projects was not monitored until the end of the project.

3.2 Project cost management

Project cost management is during the projects life cycle mainly accomplished in CoolPro -system. Before the target costs of the project are defined the cost estimate rows are imported from the cost estimation program TCM to CoolPro and the individual BoQ -based cost estimate rows are allocated to appropriate control accounts to form the target costs of control account. As control account labelling system the Talo80 -based nomenclature guideline is used. Talo80 -nomenclature is modified to support common procurement packages. The target is that as few as possible the invoices needs to be divided into different control accounts. In the system main group 0 is consisting designing an constructor costs. Main groups 1-6 include direct costs of construction parts, group 7 includes HVAC-system costs and other appliances. The costs not tied to any specific task are allocated to the main groups 8 and 9 on cost estimation.

3.2.1 Project cost estimation

The first cost estimation is formed based on BoQ or if there is not detailed quantity data available the cost estimate is defined by using EstiModel that estimates the costs based on certain properties of the project. The BoQ provided by quantity surveyors is transferred to TCM-program and every BoQ line is given an estimated cost. Cost estimations are based on recorded data from previous projects and preliminary offers bid form vendors. The preliminary offers are bid of the largest purchases. The goal is to define about 60 % of total costs by using information gathered from preliminary offers and the rest is based on historical cost data updated by cost engineers and procurers.

The needed hours of work to complete certain quantities is estimated based on standard consumptions determined in RATU. Sometimes cost engineers modify RATU consumptions based on their own knowledge. In these cases the quantity is often relatively small and therefore relatively slower to complete and cost per square meter is more expensive than for bigger quantity.

The first cost estimation phase is ended when the cost estimates are transferred to CoolPro -system and the cost estimation rows are gathered under specified control accounts according to control account guideline. Each control account is composed of three different type of costs; work, material and subcontract costs. Each cost type needs to be evaluated based on how the work is planned to be accomplished. The cost estimation transferred to CoolPro forms the cost target of the project. Cost target is by its name the target costs the project is heading to. All the occurring costs during the projects duration are compared to target costs. Target remains mainly invariable during the project, but sometimes the procurement packages are differing from the planned or work planned to be accomplished by own employees if bought from subcontractor. In these cases the target costs need to be modified to current production plan to maintain comparable target.

3.2.2 Project budget and cash flow planning

Projects budget is determined based on cost estimation. The cost accrual over the project duration is determined by using standard cost accrual curves. The CoolPro system have three different standard curves for three different project types, additionally the normal curves created for residential unit as a study project can be used or totally new curve can be created for a specific project.

The chosen cost accrual curve is used to determine the payment plan of the client. In contracts payments are often tied to completion of certain tasks or certain tasks in certain locations. Often clients have their own terms for payment plan for example when the roof is waterproof maximum 60 % of the total project sum can be charged. But often clients are ready to negotiate about the payment plan. The payment plans are determined as front-end-weighted as possible within the terms of client to ensure the positive cash over the project duration. Payment plan is the main way to effect on cash flow. If the payment plan is made carefully keeping the cash positive does not require any additional effort but to make sure that payments are charged according to schedule.

3.2.3 Project cost monitoring and control

The basis of project cost management is updated cost and income forecast. Forecast is updated once a month and it offers real time estimate of the profitability of the project. Fundamental practise for monitoring the costs of the project are regular follow-up meetings, where the project's latest cost estimation is audited.

According to interviews of site engineers and construction managers the cost monitoring is generally site engineer's responsibility. The actual costs of the project are booked according to same control account logic as the cost estimate is calculated. Forecasting the end cost is done for each control account and cost type separately. For each cost type the realized cost and incoming costs are determined as specifically as possible at a time. Site engineers follow costs and gather new information about costs from incoming offers of purchase packages, agreed unit prices or total price of subcontracts, actual cost accrual, updated information about quantities and incoming change or additional orders. The construction site foremen can offer cost information varyingly. Some of the foremen are very interested of the costs of their own tasks and know exactly how much they have used money and how much they have left to complete the task they are supervising. But some of the foremen are not interested of their budgets and don't follow their costs at any level.

When preparing the cost forecast the cost effect of change or additional orders is be taken into account in the control accounts. The costs of change orders and additional orders are added to control accounts and the target cost of whole project as well as the total chargeable costs grow with the sum of order's costs and agreed price.

3.3 EVM and project progress monitoring

Currently the earned value management is not comprehensively used as a project management tool at NCC Suomi and currently there is not any other development projects going related to EVM besides this thesis. Project's cost and schedule progress and performance is monitored and managed with one tool utilizing some features of EVM but mostly the progress monitoring is accomplished with other tools.

The tool currently used is based on Master's thesis of Rautavaara (2015) for NCC Rakennus Oy. She studied the effect of project's diverse properties to the cumulative cost curve and researched cumulative costs of 139 projects and as a result created standard cost accrual curves for various diverse residential, refurbishment and commercial projects. According to Rautavaara (2015) the building type specified standard cost curves represent cumulative cost accrual well and the curves can be used to forecast the cost accrual over the construction phase and schedule analysis based on cost accrual is possible. Thesis was done for the unit of Lahti and as further analysis same kind of research was done for residential unit in capital area. Research resulted standardized cost accrual curves for residential projects with diverse properties. The total cost accrual of the project can be compared to the standard curves. These standardized cost accrual curves allowed the EVM-like way of monitoring progress to be performed. Occasional cost accrual checks are done where the actual cost accrual of the project is compared to the standard curve of the project type. In these check the extensive deviations from normal cost accrual curve can indicate either incorrect cost estimate or end date in the project properties in ERP-system. These checks are not performed by the project managers and the tool is not available for them. This tool does not take into account the planned and actual physical completion in any other way than importing only start and end dates of the project from the properties set at the beginning of the project. None of the changes during the project are reflected to the information of the tool, since it may offer false information if the actual and date or cost estimate changes dramatically. Some false information from project properties have been found with help of this tool, but it is not used for steering the project.

Project report gives state of completion percentages for costs, total quantities completed and time of the total construction time consumed for the whole project. The costs not tied to any specific task are allocated to the main groups 8 and 9 on cost estimation. Upcoming new project report presents the actual cost accrual and the forecast of these indirect costs. Report assumes that cost accrual is linear over the project and the forecast of the upcoming costs is always calculated as the rest of the total costs estimated will accrue linearly to the end of the project. This new project report is not yet tested or taken into use. On more specific level costs are not compared to completed schedule tasks by any report or project analysis tool. Thus the project managers, responsible site manager and site engineer should be aware of the state of their projects and be able to evaluate if the costs are accumulating normally with respect to physical progression.

On task level the schedule and cost monitoring and comparison is assumed to be analysed by the site foremen. According to the interviewed personnel the awareness of especially the costs of tasks is highly variable between site foremen. Some of the foremen follow very strictly their accrued costs and compare it to the completed quantities but some are not following costs at any level. Therefore the knowledge of overall performance on task level can vary noticeably between foremen.

4 Proposed EVM application

Project management tool utilizing earned value management theory for NCC Building was created. Tool is a view at already utilized project information system Qlikview and it offers information about schedule task's cost variance and schedule variance. As noted at the theory section, implementing EVM should not require any additional planning and all the information should be available if the project is planned and monitored on good level. In the case company all the data needed for earned value analysis is already existing in company's information systems as a result of schedule and cost monitoring. Proposed system creates EVM graphs automatically based on the information gathered from the information system of the company.

System automatically gathers the information about enrolled costs, latest cost estimate, scheduled statuses of completion and current status of physical completion. Based on the information gathered the cumulative planned value, earned value and actual cost graphs are drawn to visualize the status of the project and relevant variances and indices can be calculated. System alarms if the project's progress deviates from the plan significantly. The deviation is determined by the variances and alarms generated if variances exceed accepted values.

To make the system work properly standardized way of archiving schedule files and name and code the schedule tasks needed to be determined. After the standardized way of saving information was created the baseline planned value for comparison was determined. Because project specific planned value curves can not be used standardized curves based on previous projects were determined for the tasks. When the baseline is determined the earned values and actual costs accumulated can be compared to baseline and variances analysed. Based on the variances system gives warnings about deviation.

Because of timely matters only five schedule tasks were chosen to be followed and tested in this master's thesis. The chosen tasks are;

- filling and painting
- fixture installation
- parquet/laminate floor installation
- wooden door installation
- battening

These tasks are chosen because they are composed of quantity items of single control accounts and the physical progress is simple to monitor relatively accurately because these tasks are mostly performed in apartments rather than in common areas.

Created tool was tested in three projects in testing phase. The projects and the basic information about the size of projects is presented in the Table 2 below.

Table 2: Test projects

	Borgiströminmäki	Kaskelantie	Perilänniitty
Gross area	8 599 m2	8 830 m2	9 870 m2
Total area of apartments	5 016 m2	5 832 m2	6 661 m2
No. buildings	2	2	1
No. staircases	3	2	3
No. floors	6	8	8
No. apartments	108	127	126

Borgiströminmäki is composed of two buildings A and B. Building A includes two staircases A1 and A2. building B has only one staircase. Both buildings are 6 floors high, but all the floors are not identical. As it is presented in Table 3 locations have varying amount of apartments with varying sizes.

Table 3: Borgiströminmäki locations

Staircase	Floor	No. Apartments	Apartment floor area
A1	1	5	211 m2
	2	6	253 m2
	3-5	5	258 m2
	6	4	159 m2
A2	1	2	89 m2
	2-6	8	338 m2
B	1	1	45 m2
	2 - 6	7	332 m2

Kaskelantie includes two buildings A and B with one staircase each. Both buildings are 8 floors high. There is some variation between locations but mainly the locations are identical (Table 4).

Table 4: Kaskelantie locations

Building	Floor	No. Apartemts	Apartment floor area
A	1	5	260 m2
	2-8	9	442 m2
B	1	7	319 m2
	2-6	8	363 m2
	7-8	6	251 m2

Perilänniitty is one eight storey building composed of three staircases A, B and C. All staircases have apartments on identical floors 2-8, first floor is composed of common areas and technical spaces an the test task do not occur there except for filling and painting. The floors from 2-8 are identical on every staircase and the staircases are very similar when compared to each other (Table 5).

Table 5: Perilänniitty locations

Staircase	Floor	No. Apartments	Apartment floor area
A	2-8	6	319 m2
A	2-8	6	309 m2
C	2-8	6	324 m2

The correctness of data offered by the EVM tool was evaluated against the control charts and feedback was gathered from the construction managers and site engineers of test projects. They were also asked to evaluate the reasons of the deviations visible in the created graphs.

4.1 Standardized way of planning and archiving schedules

To make the automatic data collection possible standardized way of archiving the schedule files was created and implemented. While collecting the data for standardized cost accrual curve presented later, it was noted that the names and codes for schedule tasks are varying noticeably between projects. This creates a difficulty for automated system because it cannot create comparison between schedule task and control account if there isn't any standardized feature to identify the schedule file to use and tasks to compare. To solve this problem a standardized way of archiving schedule file versions was proposed. To ease the comparison between control account and schedule task and a schedule template for residential buildings was created with standard names and codes for the tasks.

The problem on archiving schedule files is that there are often many different version saved of one schedule. The system does not know which one of the schedule files it should use for analysis. The archiving system Pro3 keeps record of version, and the whole version history of one file is saved and any of the previous versions can be restored. It is recommended to use the version history instead of adding new file after every update on schedule. By saving schedule files like this there is no need for multiple schedule files and system can use the only file available. If still multiple schedule files are needed for some reason should the schedule file used for monitoring be marked with text "monitored". From specified "monitored" text on the name of the file system knows that it is the file currently used for schedule monitoring and utilizes the information from that file.

Schedule template was created to standardize the names and codes of schedule tasks. This makes it possible to create a permanent mapping between control accounts and schedule tasks when most of the tasks are always on the same code. Schedule template is created based on control account guideline which is based on "Talo 80" -nomenclature. The target is that each task covers either the whole control account or that the task is a part of bigger unity of tasks covering the control account together.

As an example of task covering the whole control account is laminate floor installation. Laminate floor have their own control account number 5642 and all the quantities included the control account are included in single schedule task. In this case the comparison between physical completion to cost accrual is simple because one schedule tasks tells the physical completion and it can be compared to single control account. Then again painting is an independent tasks that is crucial to be on the schedule on its own but it belongs to the filling and painting control account number 5800. Filling and painting form a control account together because they are often accomplished by the same subcontractor and the contract boundary between filling and painting is wanted to be mitigated. Therefore both filling and painting is included in one contract. In current cost management system order and thus contract can be assigned for more than one control accounts, but in practise it is easier to assign all the invoices from one subcontractor to one control account since the invoices can sometimes be difficult to assign accurately. The same logic is used in earthworks. Earthworks is one control account in cost estimation because all the tasks included in earthworks such as excavating, mining, filling and underground drainage systems are often done by one subcontractor. But all the tasks included in earthworks are planned and monitored as separate tasks in schedule. In cases like filling and painting and earthworks completion rate on single task can not be compared to the cost accrual on control account but the completion rate combined of all the including tasks can. Thus the total completion rate of the control account must be able to be determined automatically from the states of separate tasks.

Currently invoices registered on any control account can not be automatically targeted to separate quantity items of the control account. Thus the cost schedule comparison is possible only on control account level not on quantity item level. In other words if control account includes quantities that are divided to several schedule tasks the cost accrual of separate tasks can not be followed only the cost accrual of the total control account. This fact is taken into account when establishing the schedule template. An example of this kind of control account is 2070 plastic thermal insulations. Materials included in this control account are assembled as a part of various schedule tasks. Separate quantity items included in control account can be specifically assigned to different tasks, but the invoices assigned to control account can't be assigned on quantity item level and therefore to separate schedule tasks. In larger scale this is not a problem since the control accounts like these are only a minor part of all the control accounts in main groups 1-7 and can be excluded from this analysis.

To effectively follow the physical state of completion of the total control account in cases when the control account includes several separate schedule tasks, all the schedule tasks included in the same control account are given the same code. For example the control account 5800 filling and painting is composed of two schedule tasks as described above. To make it possible for the automated system to find the tasks and tell it which tasks to compare to which of the control accounts, both schedule tasks filling and painting are given the same code as the control account 5800 they are compared to. Same logic is followed in earth works tasks. If users wish to add their own tasks in addition to default tasks they are instructed to use the code of the control account the costs of the task belong to.

The schedule template includes the RATU based labour consumptions and default dependencies between tasks are built in to the file. This information is included to ease the schedule planning and to guide the schedules to realistic direction.

4.2 Formulating the standardized planned value graph

Alvarado et al. (2005) stated that the Planned Value graph should be project specific, but sometimes it cannot be drawn and then the standardized curve should be utilized. In this case the project specific graph cannot be drawn because tasks are not planned accurately enough to create project specific planned value graphs. Also the information about payment plans cannot be reached from the system automatically and therefore the cost accrual curves cannot be defined according to payment plans.

Vico schedule planner offers already graphs of cost accrual if the BoQ rows included in tasks contain cost information. These cost accrual curves were not used because the cost consumption curve formulated by Vico is not taking into account material purchases done beforehand, payment plans for subcontractors or payment delays. Thus the cost accrual forecast by Vico shedule planner is assumed not to correlate the actual cost accrual.

Because of the lack of available information, planned value graphs are determined based on standardized cost accrual curves as Alvarado et al. (2005) suggested. It is assumed that the cost accrual for specified tasks is similar between projects because most of the projects use the same subcontractors and purchase the materials and labour based on same long term contracts. Thus the data collected from the previous projects is assumed to represent the normal cost accrual of upcoming projects too. This means that the shape of planned value curve is constant in every project and is based on previous projects.

The data used to formulate the standardized cost curves was gathered from the information system of NCC Building. Analyzed projects included all residential projects of AR completed after the beginning of 2013. This definition covers 102 projects of which 93 had schedule information available at the ERP-system Pro3 project file archive. Some of the projects analyzed had very few information in their control charts or some or all of the tasks analyzed weren't been monitored at all. These projects are excluded from research data either completely of partially concerning the tasks not monitored. The numbers of included projects in determining each of the standard curves for chosen tasks can be viewed from the Table 6.

Actual start and end dates of each task were collected from archived control charts and combined to registered costs for the control account corresponding the schedule task. Physical state of completion and economic state of completion were defined weekly from the beginning of the task and drawn to a graph. Data points of each project were collected to one graph and distinctly abnormal accrual curves were excluded from the analysis. At last the standard curve was determined by using the trend line -function of Excel as shown in the Figure 3. Standard curves were chosen to be sixth degree polynomial functions as those represented the data best of all the available options and had the highest coefficients of determination. The final standard curves are shown in Figure 4.

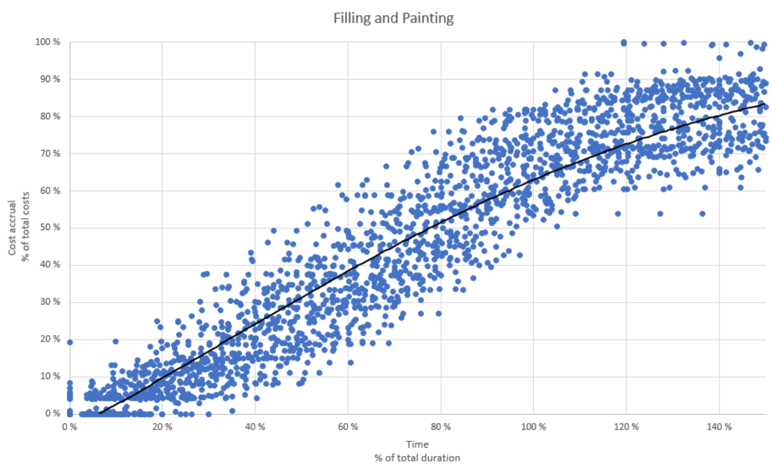

Figure 3: Trendline function used to determine the cost accrual curve of filling and painting

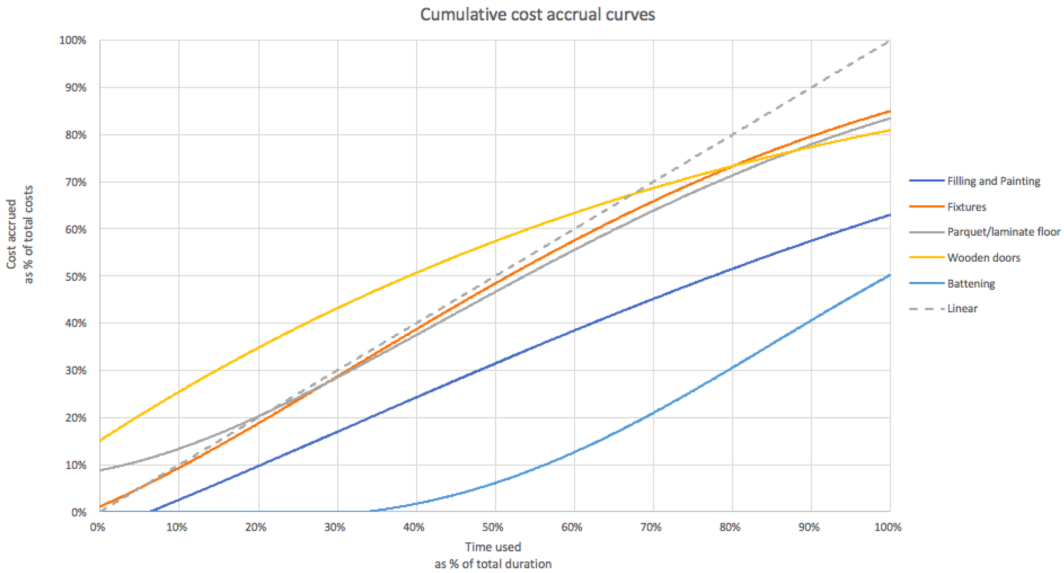

Figure 4: Standardized cost accrual curves for selected tasks

The linear curve is drawn to Figure 4 to represent situation where the cost of work accomplished is accumulated at the same moment. As can be seen the created cost accrual curves are deviating from this linear graph. The wooden door installation is noticeably ahead of the linear cost accrual. This is due to the material purchases that form the major part of the task budget since the doors are relatively expensive when compared on the cost of installation itself. In this task NCC purchases the doors before the task begins. Doors can be purchased in couple of batches and the first deliveries are received and paid before the installation can begin.

Also in the floor installation task the material purchase before the beginning of the task causes the cost accrual curve to be first slightly ahead of the linear. But because in this task the material cost is not as high when compared to the cost of installation as in door task the curve starts to follow linear soon after the start.

Tasks where the subcontract often includes the materials and installation are accumulating more according or behind to linear curve. For example the fixture task follows the linear graph since the fixture company often invoices for fixtures that are manufactured and for the installation work itself. But the fixture company does not manufacture the fixtures as early as material are ordered and therefore the cost accrual is not started as early as in the wooden door and floor installation tasks. But neither it is not easily left behind of the linear. Whereas in filling and painting task often the first invoice is sent when the first step of payment plan is met and first state of completion targets are met. Therefore because of the payment delays the cost accrual is behind the linear curve.

As can be seen in Figure 4 toeards the ends of the tasks the cost accruals slow down and in the end of the tasks all the costs are not accumulated. This happens mostly because on contracts that are invoiced based on payment plan it is often determined that the last invoice can be sent after the final clearance of the contract is held and all the claims are fulfilled. But also because of delays on sending the invoices and the acceptance process. This can clearly be seen from the graphs of fixture, floor and door installations.

Filling and painting and battening seem to have noticeably low rate of accumulated costs when the task is finished. The main factor causing the invoiced costs in the end of filling and painting task, can be that there are often tasks included in filling and painting contracts that are not monitored for example exterior painting or painting of the common spaces. These tasks are often done after the apartments are painted and they are not included in schedule and not monitored. Another possible reason is that often there are a lot of repairs to be done after the task itself is completed. These repairs are made with hourly payment and they are not included in the contract sum. Also the last payment of the payment plan can often be invoiced very late since the repairs can sometimes last until the whole project is finished.

Factors affecting the low rate of accumulated costs of battening can be that as was noted while collecting the data contractors have been paid only by few payments and the contractors are not that keen on invoicing their work immediately. This may be due to relatively fast task and small total sum of contract.

The error from standard curve was calculated for every point. Median error and standard deviation were calculated for every curve. The smaller the median error and standard deviation are the better the standard curve represents the data. The recorded overall median errors and standard deviations are presented in a Table 6. Error points were plotted to graph to clarify the error is evenly distributed on both sides of the neutral axis. If the error points would have been only on one side of the zero it would have indicated that the trendline is not viable. The error distribution should be even on both sides of the zero. The error distribution of filling and painting can be seen in Figure 5. Because the distribution is even it can be concluded that the standard curve is applicable.

Table 6: Error limits for tasks

	Filling and painting	Fixtures	Parquet/laminate floor	Wooden doors	Battening
Projects analyzed	79	78	69	74	56
Median error (ME)	6,08%	9,20%	9,08%	12,02%	5,36%
Standard deviation (SD)	8,45%	9,04%	7,95%	10,90%	11,67%
Alarm limit (ME+SD)	14,52%	18,24%	17,03%	22,92%	17,04%
Points inside ME+SD	85,48%	78,79%	79,60%	82,95%	74,77%
Coefficient of Determination	0,92481	0,89281	0,88915	0,78073	0,85128

For further analysis the curve was divided into 20 parts after every 5 % on

Figure 5: Error distribution of filling and painting

time axis and median error and standard deviation were calculated for each part separately. Inside the median error is 50 % of the points and inside median error added with standard deviation is about 80 % of the used points. These median error added standard deviation values will be used as a base data for sixth degree polynomial trendline curve to be used as alarm limit for the cost monitoring. In Figure 6 the actual values of median error added with standard deviation are drawn with solid line and the trendline determining the error-limits with dash line.

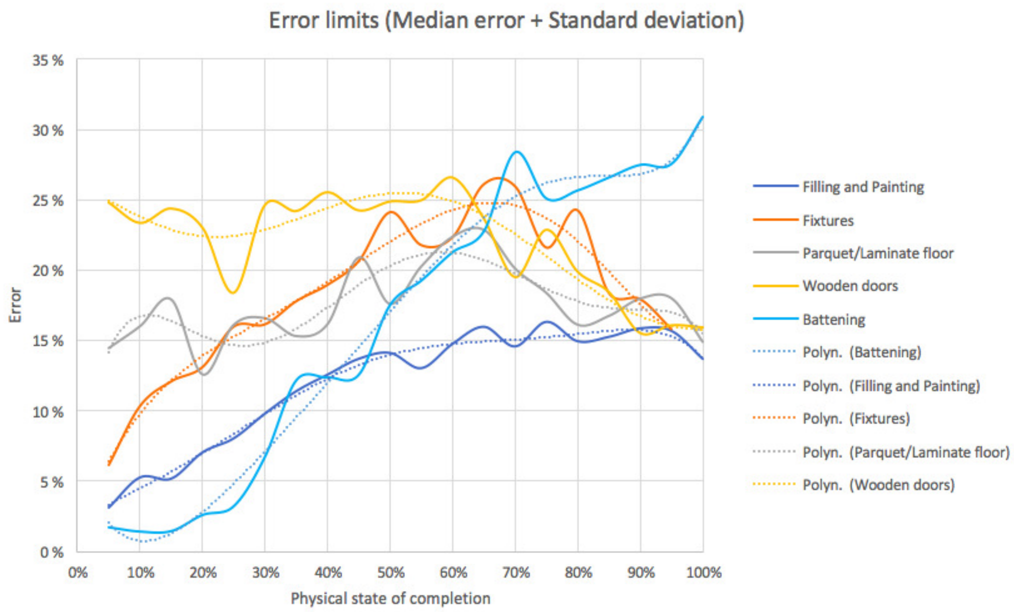

Figure 6: Error limits for tested tasks

As can be noticed from the Figure 6 trendlines level the alteration between certain points and show the trend of the error better. Whereas all the other task seem to have smaller error limits in the end of the task, error limit of battening increases towards the end of the task. This is a consequence of highly variable cost accrual curves of recent projects.

4.3 Creating the EVM parametrics

All the data needed for plotting EV and AC is already existing as a result of schedule and cost monitoring. The data needs only to be processed by the system and then analyzed againts the PV as project baseline.

Planned value graph was created either using only scheduled start and end dates of the whole schedule task or by using the scheduled states of completion in location level. If only the start and end dates of the whole task are used the dates are set as the start and end dates for the task specific standard curve and the expected states of completion are set according to the curve. Note that in this model the standard curve does not take into account the non-linearity of planned production. Planned value curve expects that production is progressing linearly between its start and end dates. More precisely this means that if there is planned breaks in the production flow, at some point the resources of the tasks are increased or decreased notably or for some reason the production is not proceeding at same speed the model can not take it onto account. The curve created using this more simple method is later called "rough PV".

More accurate planned value curve can be created by using the scheduled states of completion based on locations. Since the schedule determines the quantities and start and end dates location specifically the states of completion of the entire task can be calculated on each of the dates. It is assumed that in one location the work is proceeding on constant speed. This way of creating planned value graph takes into account planned breaks in workflow and differences in production speed. If the task is assumed to be discontinuous or the resources or working speed is variable over the task this planned value graph adapts to the production speed changes. Planned value graph created using location specific start and end dates is later called "accurate PV".

Planned value represents the expected cumulative cost accrual over the duration of the schedule task. Planned value curve presents the cumulative cost accrual as a function of time. Planned value formulated as a standard curve represents a cost accrual as a function of state of completion of normal AR's project. It must be kept in mind that it does not represent a perfect or desirable project. This means that in this testing the recorded level of cost accrual is acceptable and any targets are not set. In further tests targets for cost accrual could be set to guide the operations on desirable direction.

Earned value graph gets its information from the last saved schedule file's control chart. Based on the coded tasks system searches the right task from the schedule file and imports its completion rate. Imported completion rate is inserted to the standard curve equation and as a result the current earned value is received and compared to planned value and actual costs.

Actual cost graph is simply composed by collecting data about actual cost accrual weekly. Costs are registered to system after the approval of construction site personnel. Due to the approval procedure and payment delay the costs are registered with time delay. The delay is insignificant because formulated standard curves include same delays due to the information used as initial date.

4.4 Alerts

Alerts are meant to give signal for site managers to take a closer look into a task and investigate what is the reason for abnormal behaviour of EVM graphs and start to plan control actions if needed.

System gives cost variance alerts when the cost variance is above the task and completion rate specific error-limit. Error-limits are determined by drawing a sixth degree trendline-function for median error added with standard deviation over time. The recorded median error added with standard deviation is used as error-limit because this is the area where most of the previous projects had their cost accrual and it is seen as adequate.

Since the cost variance is calculated as the difference between earned value and actual costs. If cost variance is negative the actual costs are bigger than earned value and the task is running over budget. The actual task and state of physical completion specific error-limit can be seen in the Figure 6 drawn with dash line. In this figure the actual values of median error added with standard deviation are drawn with solid line and the trendline determining the error-limits with dash line.

Because of the chosen error-limit, cost variance alert does not always indicate problem, it indicates that task is proceeding differently compared to majority of previous projects. Because the planned value graph is based on historical data, not the payment plan of current task, the system might alert unnecessarily if the payment plan differs considerably from normal payment plan.

Schedule alert is given when the schedule variance is above 7 days. Since control charts are updated weekly the schedule variance of 7 days then includes the possibility that the information is already a week old and updating the chart fixes smaller variances. The start and end dates are also often determined on accuracy of one week. If the chart is updated recently and the schedule variance is over 7 days control actions need to be taken.

The schedule variance used is formed according to earned schedule theory instead of according to earned value theory because of the problematic described in chapter 2.3.3.

5 Testing results

System created EVM graphs based on information gathered from ERP-systems. Mostly any problems didn't occur but there were some aspects that needed to take into account in production planning and while creating EVM analysis. This chapter is consistent of the notes that were found while analysing the graphs drawn by the system. This chapter end with the summary of the feedback gathered from construction managers and site engineers.

5.1 Observations and problems

One of the problems during the creation of earned value analysis was that at Perilänniitty the quantities of schedule tasks were not location specific. The quantities were imported only on project level and the system wasn't able to calculate the scheduled or accomplished states of completion. The problem occurred because the system calculates the states of completion by using the location-based quantities and scheduled start and end dates. In this project the information needed was not available and the calculation could not be performed. This problem was tackled by making an assumption that the quantities are distributed evenly among the relevant locations. This assumption leads to another assumption that the duration of each location is similar. This may lead to errors if the location are not similar and the durations are actually varying between locations. But in this case as it was presented earlier in Table 5 the locations in Perilänniitty are very similar and this assumption is safe. But since project planning should be performed with location specific quantities this problem should not occur if the project planning is performed as instructed. The earned value graphs drawn based on the assumption can be seen in Figure 7.

As another note the planned value curve to be used as project baseline for calculating time variance needs to be as accurate as possible and relate to the latest project plan. The variance between rough and accurate PV curve were notable in some cases and time variance when compared to rough PV curve gave misleading information about project's schedule performance. Another note about the baseline graph to be used was done while analysing the results of Borgiströminmäki. Since most tasks of Borgiströminmäki were remarkably late the projec's management team had created a detailed plan on how they will catch the end dates of the original schedule. It was noted that the original schedule was not worth monitoring and the production should be monitored against the detailed plan. More about varying planned value curves is discussed on the next subchapter.

One problem of EVM is that because EVM is so closely tied to completed work the cost accrual after the work is completed can not be foretasted or monitored against any baseline. As was noted while determining the standardized cost accrual curves even up to 50 % of the total cost of the task is still remained to be accumulated after the task is completed. This may cause uncertainty on cash flow forecasts and analysis.

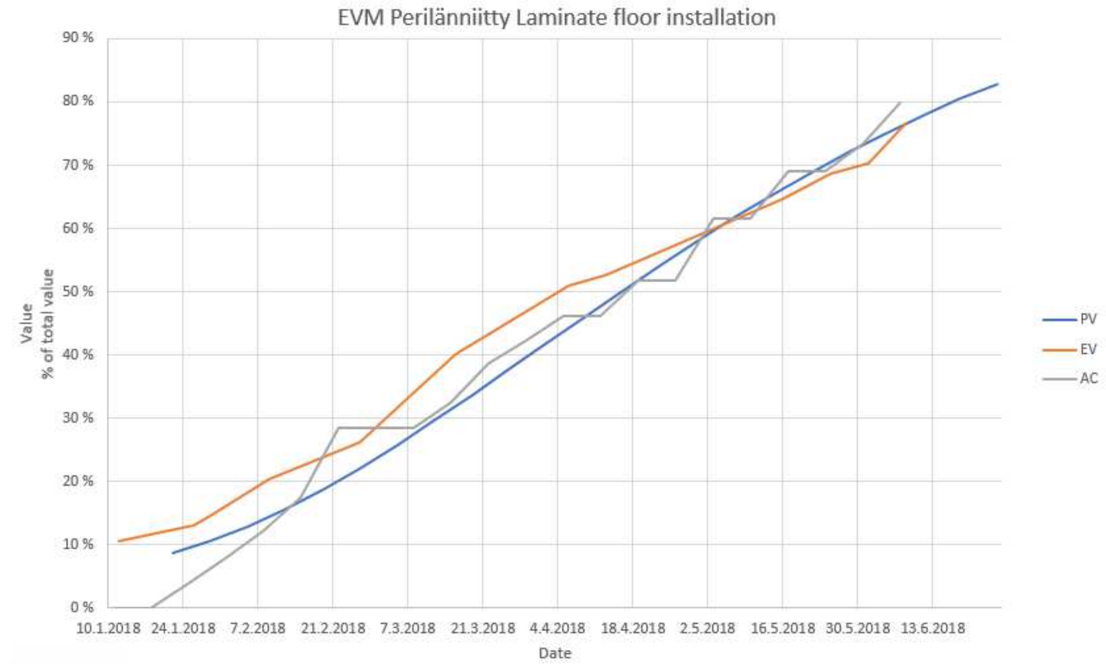

Figure 7: EVM Analysis of laminate floor installation of Perilänniitty

Cost variances for all monitored tasks of test projects were calculated and presented in graph with state of completion specified error limits. If the cost variance is above error limits the system generates warnings. In these cases the reason for abnormally accumulating costs is tried to find with help of projects management team.

5.2 Time variance and planned value graphs

Time variances were calculated as a horizontal time difference between planned value and earned value according to earned schedule theory. The time variances over time were drawn to graphs to be able to analyze trends. Time variance was calculated for both rough and accurate planned value curves to find differences. In the case of Borgiströminmäki the time variance was also calculated for the accurate detailed plan PV curve to see the variance to newest plan.

Both ways of creating planned value curves were tested. Some of the tasks of test projects were planned to maintain the constant workflow throughout the task, but some had breaks in workflow and the varying production speed. As it was expected on tasks that were planned to be continuous over all the locations and had constant resources and working speed the rough PV is deviating from the accurate PV only slightly. Conversely the tasks that were planned to be highly discontinuous or the working speed was varying noticeably between locations had the largest deviations between rough and accurate planned value.

The best correlating rough PV and accurate PV was found from the test project of Perilänniitty from the fixture installation task. As can be seen from Figure 8 the task had only two short breaks due to Easter holidays and short startup delay of second staircase. The breaks had durations of 7 and 3 days. Otherwise the task was planned to be proceeding on constant resources and working speed.

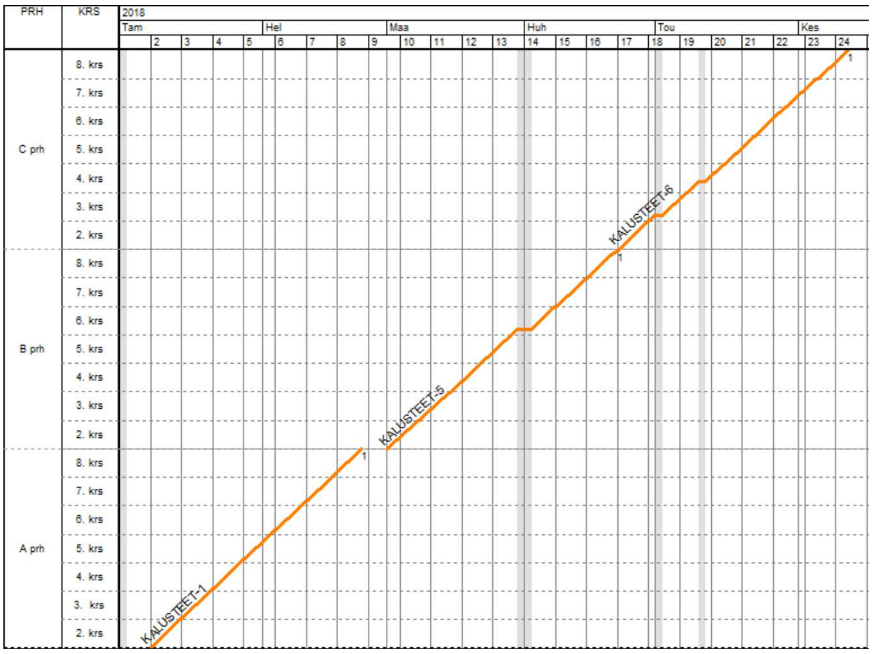

Figure 8: Schedule of fixture installation of Perilänniitty

On this task the absolute value of difference between rough and accurate planned value curves was 0,65 % on average and the largest difference was 2,96 %. The The largest difference occurs before the longer break indicating the accurate PV being ahead of rough PV. Vice versa after the break rough PV is ahead of accurate PV (Figure 9).

Largest differences between rough and accurate planned value were found from the curves of wooden door installation of Kaskelantie. The schedule of wooden door installation is very discontinuous and can not be described as linearly continuous as can be seen from the Figure 10.

On this wooden door installation task of Kaskelantie the average of absolute values of difference between planned values was 4,18 % and the largest difference was 14,27 % just before the longest break in workflow indicating the accurate PV being ahead of rough PV (Figure 11). The graph presents clearly the almost four weeks break in production as well as the shorter breaks too. In this case the accurate planned value graph points out that the value is not growing while the work is not progressing while the rough PV graph still expects the value to grow.

The reason why the difference between accurate and rough planned value was pointed out was that in one of the cases according to control chart the

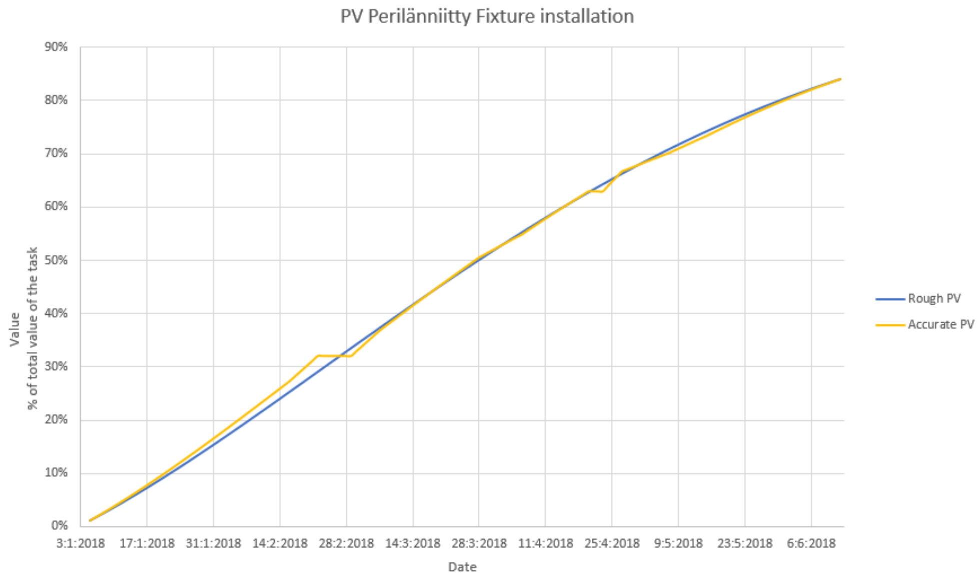

Figure 9: Rough and accurate planned value curves of fixture installation of Perilänniitty

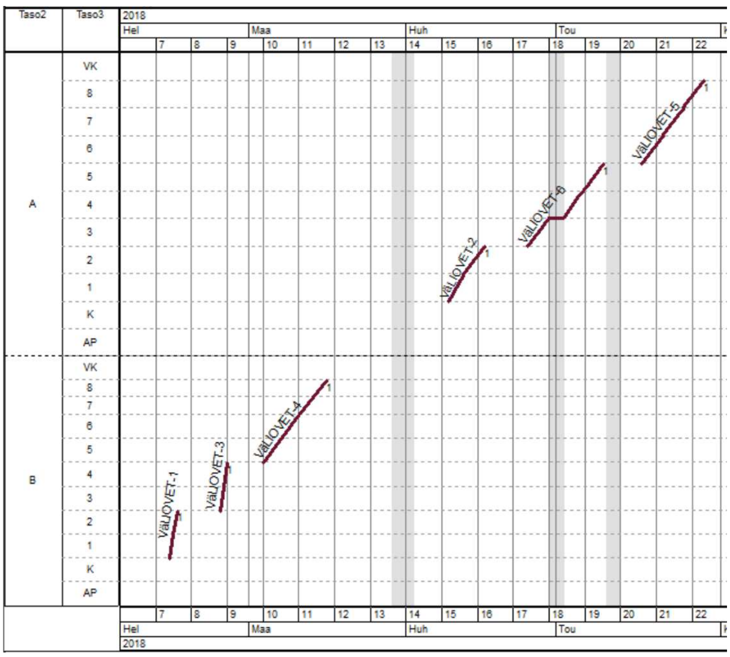

Figure 10: Schedule of wooden door installation of Kaskelantie

task was progressing on schedule, but time variance calculated based on EVM measures was indicating the task to be behind the schedule. The reason was that accurate and rough planned value had a 15 day's difference at that time. From the Figure 12 can be seen that the earned value is following strictly the accurate planned value graph, but the difference to rough planned value is noticeable.

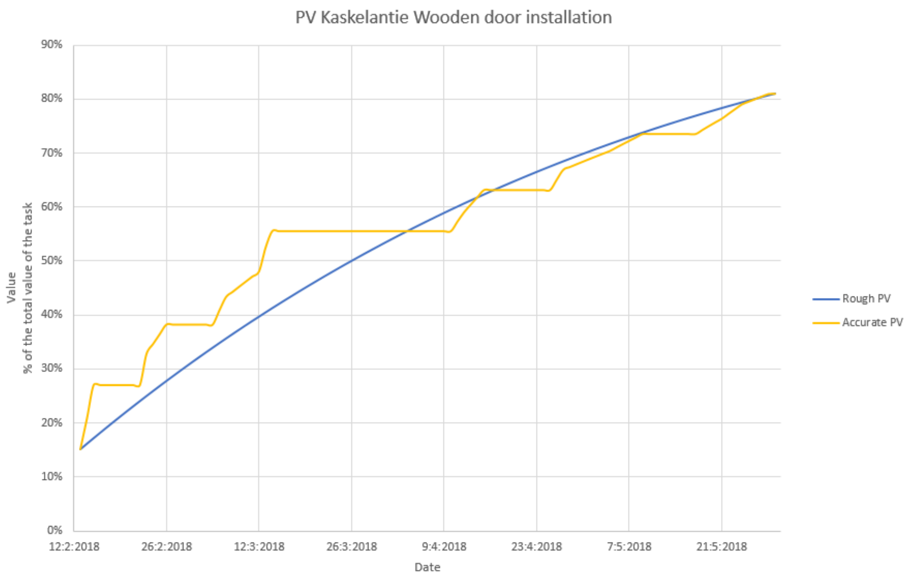

Figure 11: Rough and accurate planned value curves of wooden door installation of Kaskelantie

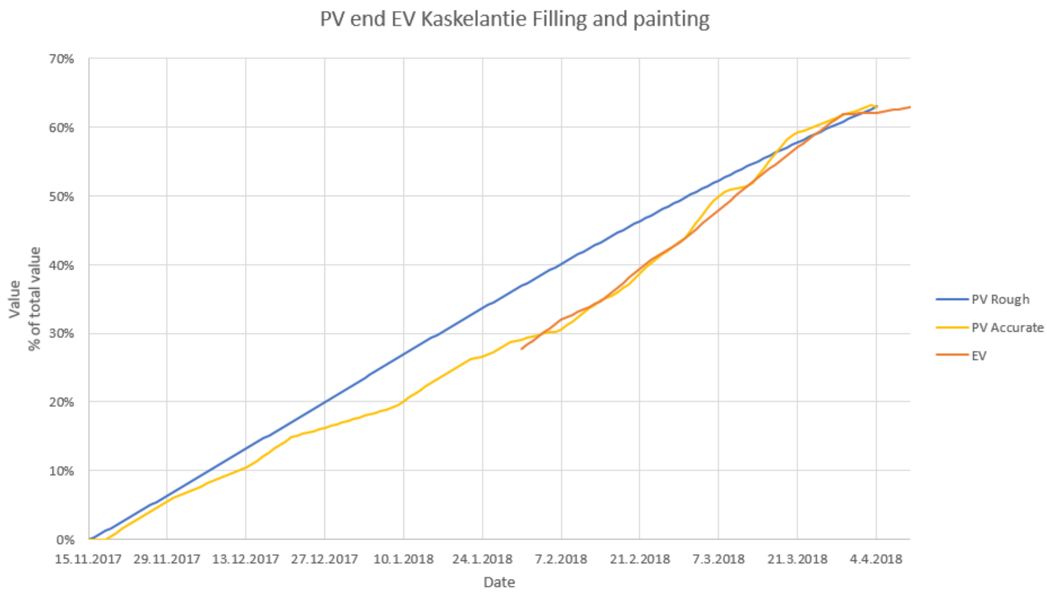

Figure 12: Rough and accurate PV's and EV of filling and painting task of Kaskelantie

Time variance comparison points out the same observation. The time variance when EV is compared to accurate PV has noticeably smaller values than time variance calculated as a difference between EV and rough PV (Figure 13). Other cases that had noticeably deviating accurate and rough planned value curves pointed out a same aspect, but this one was the only one where time variance calculated with rough planned value offered really misleading information.

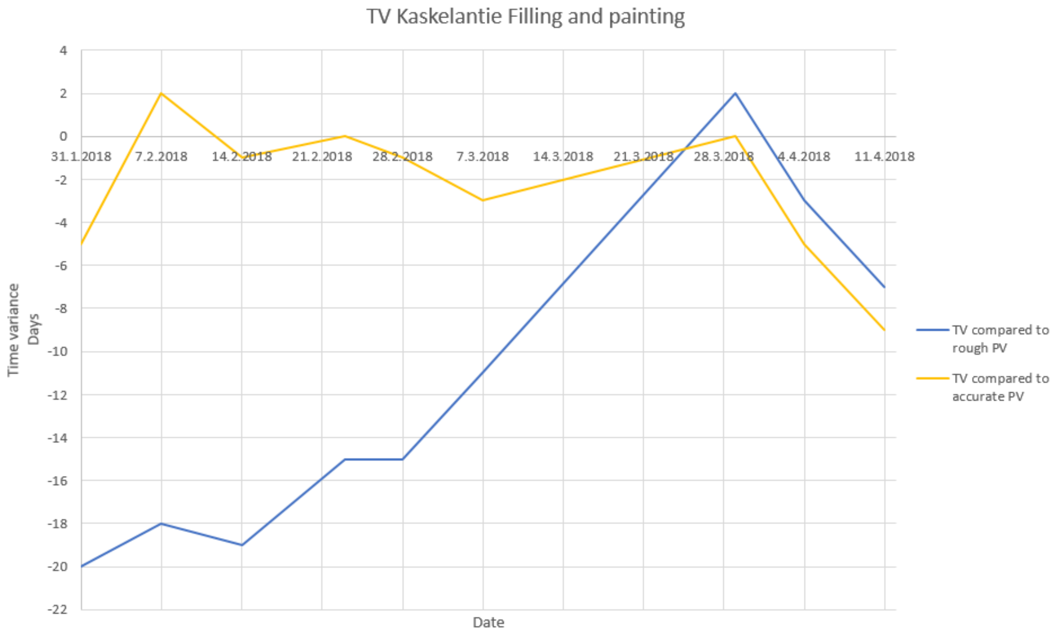

Figure 13: Time variances of filling and painting task of Kaskelantie

The another aspect that needs to take into consideration with the used baseline was noticed while analysing the graphs of Borgiströminmäki. Most of the tasks of Borgiströminmäki were delayed from the original schedule. The project's management team created a detailed schedule to catch up the original end dates of the tasks. At first the time variance was compared to the original schedule and the variances were up to 45 days. After it was noted that detailed schedule was created the system was turned to monitor the time variance against the detailed schedule. The EVM analysis with both planned value curves the accurate original PV and accurate detailed schedule PV can be seen from Figure 14. The comparison to catch up plan gives more information for project managers about how the catch up plan can be met since it is know that the original plan can not be met any more by any chans.

The time variance comparison to both original planned value and detailed schedule planned value was performed and there can be seen that the project has stayed on the detailed plan and eventually is catching up the original end date (Figure 15). This also stands for following the latest plan available and updating plans if major deviations can not be avoided.

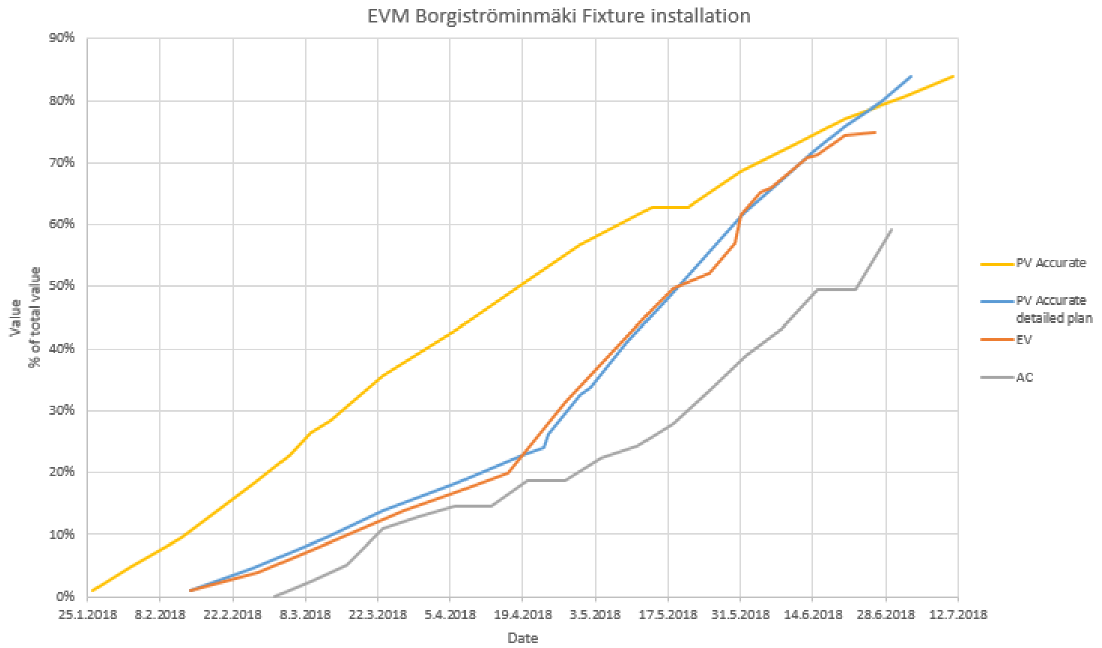

Figure 14: EVM of fixture installation of Borgiströminmäki

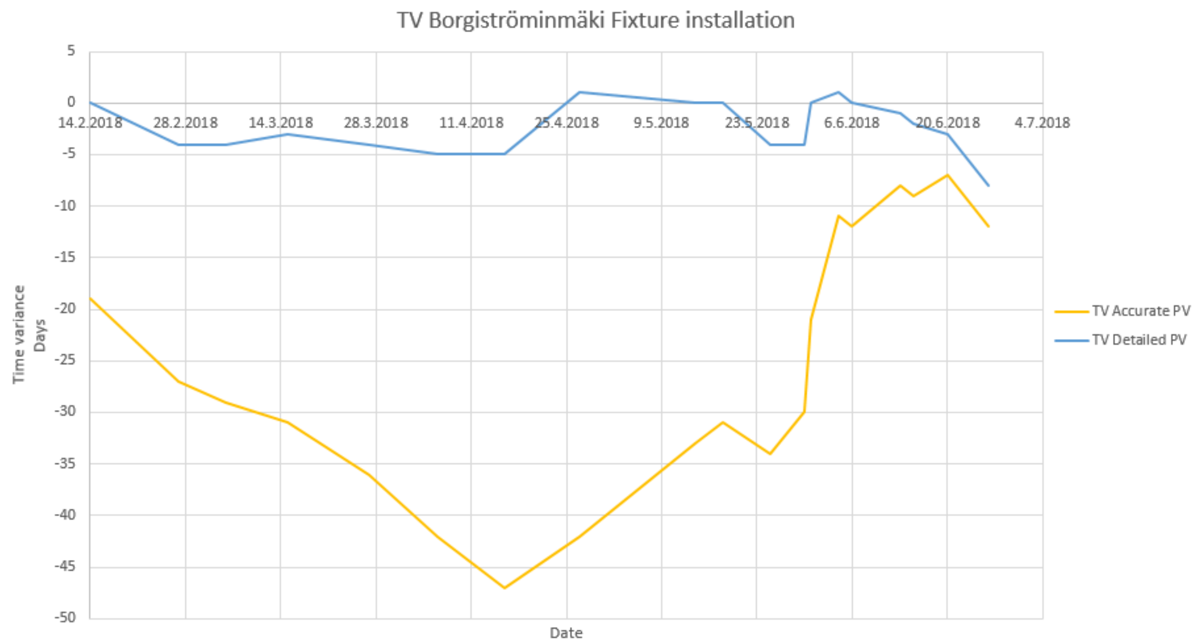

Figure 15: Time variance of fixture installation of Borgiströminmäki

5.3 Cost variance and alarms

Cost variance was calculated as a difference between earned value and actual costs. Cost variance over time was drawn to a graph with state of completion specific error-limits. If cost variance is on positive side over the error limit, indicating the costs are accumulating too slow the system gives a note to check if everything is okay and any invoices are not stuck on accepting systems. If the cost variance is on negative side over the error limit indicating the costs are accumulating too fast, the systems gives alarm. In this case should be checked if invoices are on right control account and the forecast of the control account is valid.

Any major cost overruns or too slow cost accumulation was not recorded exept from battening. Battening could be only followed at Kaskelantie and Perilänniitty. Especially at Perilänniitty the cost accumulation was highly deviating from the earned value graph and planned value graph. the deviation from the earned value can be seen in Figure 16. Even tough the error limits for battening task are relatively large, at Perilänniitty the cost variance exceeds the error limits notably as can be seen from the Figure 17 Any particular reason for deviation can not be pointed out. Based on invoices it seems that the control chart is outdated and the work has progressed more than control chart indicates. Since the invoices are accepted the work paid should also be done. Thus in this case the reason for deviation might be outdated control chart. Another possible reason is that in this case the subcontractor is sending the invoices earlier compared to subcontractors of reference projects. But most importantly in cases like this it must be checked that all the work paid is really accomplished and that the cost estimate is still valid.

One example of cost variation over the error limits can be found from the laminate floor installation of Kaskelantie. The EVM graphs of laminate installation indicate that the task is delayed from the planned, but the costs are accumulating according to planned (Figure 18).

From the cost variance Figure 19 can be seen that in the beginning where the task is not much delayed the cost variance is between error limits, but when the task is falling more behind and costs keep accumulating according to the schedule the cost variance grows over the error limit and system warns about too fast accumulating cots.

The reason for this behaviour of cost variance is that all the materials are ordered by NCC at once and delivered and invoiced according to the original schedule. Often tasks like laminate or parquet floor installation, wooden door installation and battening are consistent of material order and separate work order from subcontractor or own employees. In these cases the material is often purchased in couple batches for example materials needed for one staircase at a time. These deliveries are often shown as "jumps" in the AC graph as can be seen in Figure 18. Sometimes if there is storage space available on site items like these can be delivered to site and invoiced very early before the installation begins. In cases like these the impact of early material deliveries

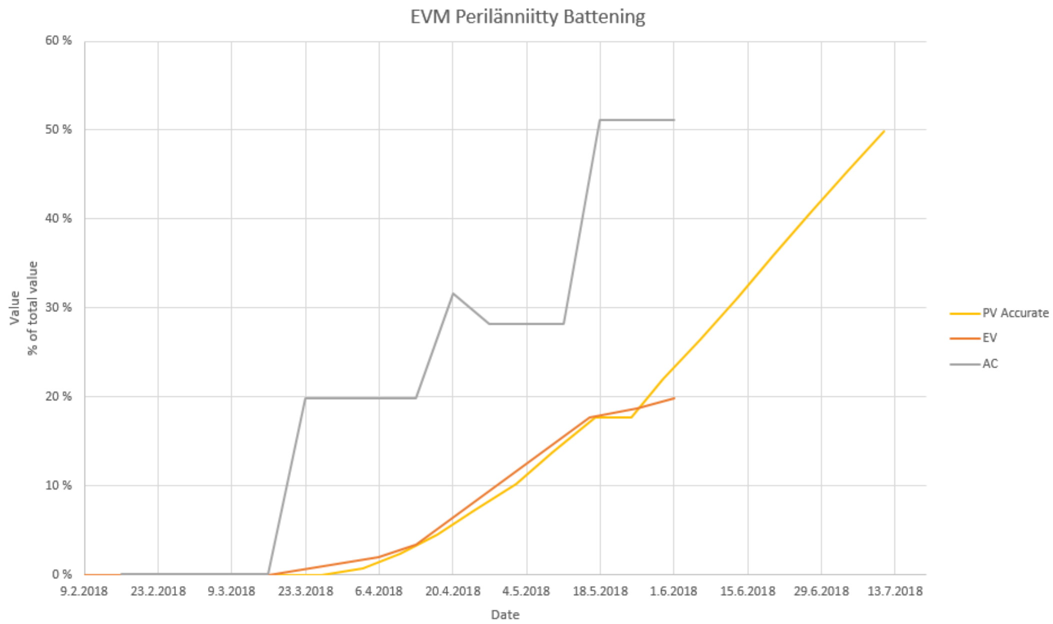

Figure 16: EVM of battening of Perilänniitty

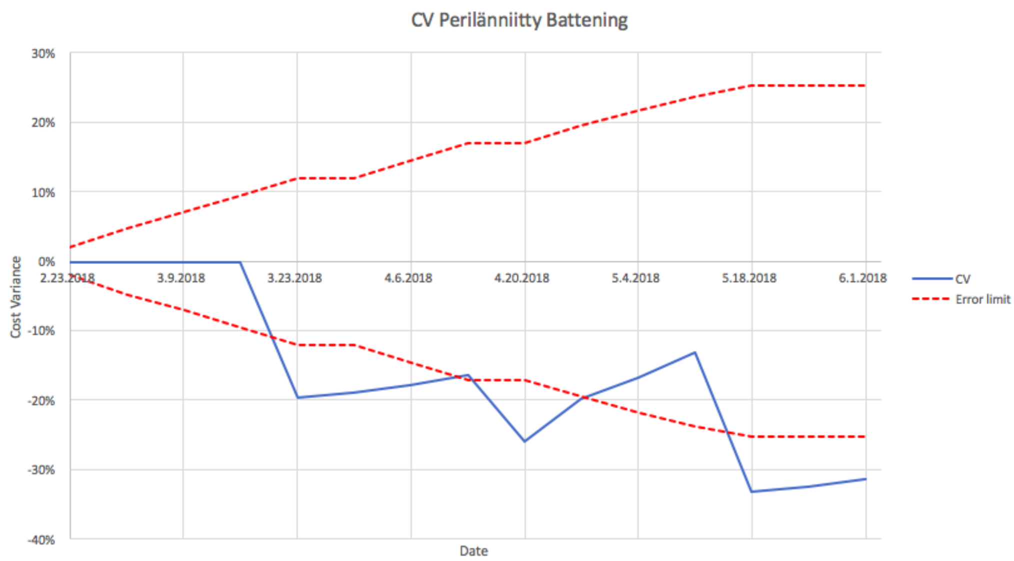

Figure 17: Cost variance of battening of Perilänniitty

needs to be taken into account. Another cause for early cost accrual at Kaskelantie's laminate floor installation is that they have had problems with drying of concrete floors and the floor installation group have been waiting and doing some additional work. This adds additional costs to original cost forecast and these costs are not taken into account the current cost estimate. In this case the cost estimate is not valid and needs to be updated.

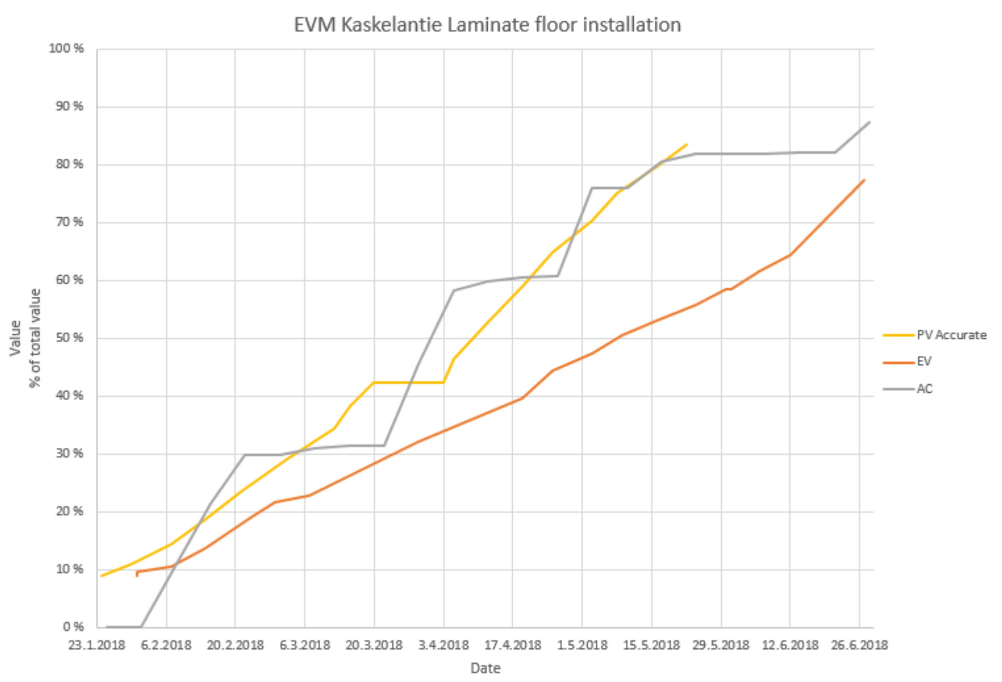

Figure 18: EVM of laminate floor installation of Kaskelantie

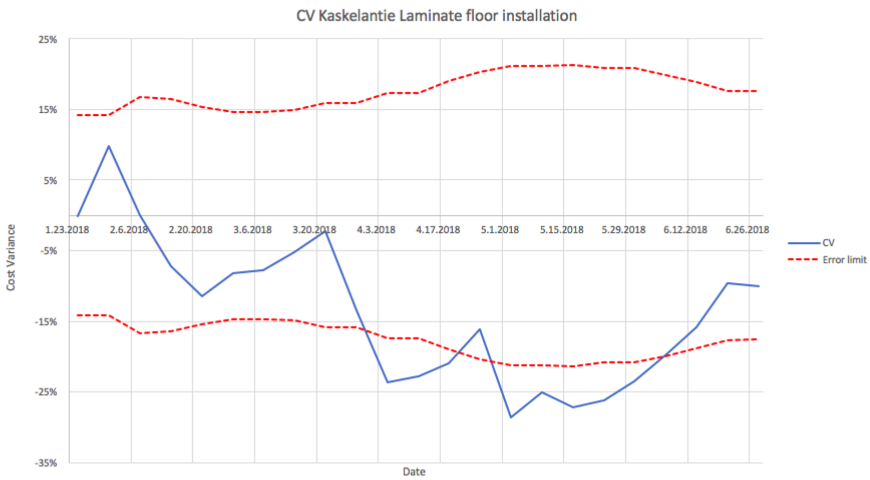

Figure 19: Cost variance of laminate floor installation of Kaskelantie

Another example from the fixture installation of Borgiströminmäki. As can be seen from the Figure 14 the costs are accumulating slower than the work is progressing. The cost variance graph shows the same truth as can be seen from Figure 20. In this case there is no specific reason for slow cost accrual. All the invoices received are accepted and paid according to due dates. The payment plan is not planned to be back end weighted. For some reason the subcontractor just haven't send invoices for the work they have completed.

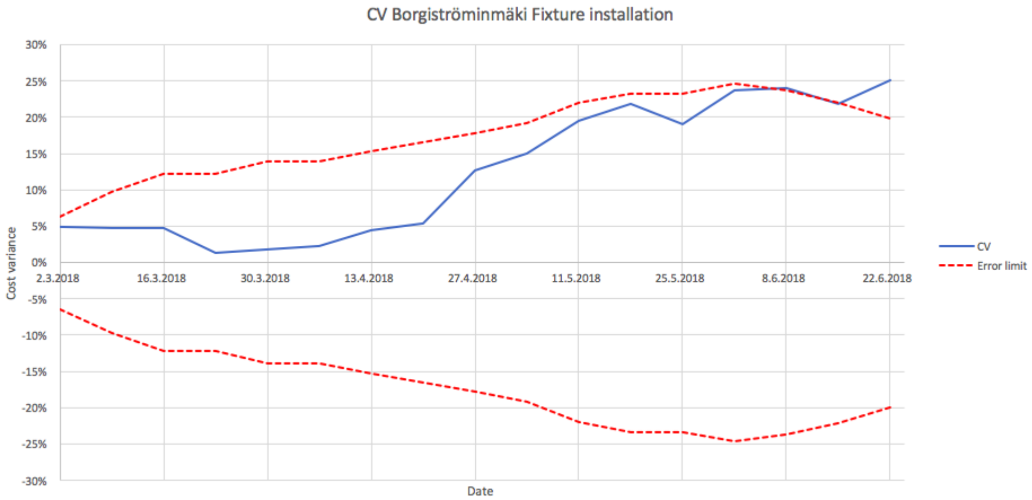

Figure 20: Cost variance of fixture installation of Borgiströminmäki

5.4 Practitioners' feedback of the EVM

Tool and the graphs of their own projects were presented to construction managers and site engineers and their opinions were collected in interviews. They were also asked to analyze the changes in graphs and evaluate the reasons for cost variances.

According to site engineers and construction managers the EV graph presented well the features on production. They were able to recognize the production problems and taken control actions from the EV graph and saw the impacts more clearly than from the control chart or flowline chart. Mostly because they saw the flowline chart with actual accomplishments as messy and difficult to interpret.

Most of the site engineers interviewed saw the created tool as useful and were interested using the tool in their work on control account level. They assumed they would use the tool in forecasting costs and updating cost estimates during the project. The tool can help on estimating costs but it can't replace the current procedure for cost monitoring and forecasting. This also gave them more reasons to update the control chart on more accurate level, since some of them felt that currently the control chart is not effectively used. They were also pleased that the tool does not require any additional work to maintain.

According to construction managers interviewed this tool offers more accurate information about control accounts and related tasks than any system currently used. They saw this as a good tool to "wake up" site engineers and foremen to check what is going on with the task if the costs are accumulating abnormally. They were also interested in comparing their projects on earlier projects and finding the reasons for deviations.

Site engineers saw that this tool would mostly be used by them. In some cases site foremen could monitor their own tasks, but mainly the following should be site engineers responsibility. If there are noticeable deviations the reasons can be discussed together with foremen but regular following by foremen is not necessary. Most of the construction managers saw this tool as useful for them and site engineers on control account level, main group level and project level. Only one of the construction managers and one site engineer saw this tool useful only on main group level, not at all on control account level.

Both site engineers and construction managers saw the benefit of evaluating the subcontractor payment plans based on EVM analysis. If some subcontractor is notices to send invoices early on every project the information can be used when negotiating new contracts.

Even tough this seems as simple way of monitoring projects, the characteristics of projects needs to be recognized and taken into account. To be able to effectively evaluate the results of this tool the projects need to be known well. But it is also the point of this tool to make site engineers and foremen to familiarise with the factors affecting deviation. Some interviewed saw this a bit difficult to understand at first, but after getting familiar with the content of graphs and variances they saw it as a good indicator of projects performance.

As disadvantages of this tool was seen that at first sight it seems a bit complex and it can be difficult to get people used to it and see the benefits of using this tool. Resistance on new programs and systems will most likely slow down the acceptance of EVM tool and the benefits must be remarkable to get the people want to use the system. As one con was also seen that the information comes late. If the payment plan is done too front end weighted for subcontractor it isn't noticed until the invoices have arrived and accepted. Also the current standard curves including both material and working costs on tasks were the materials are bought by NCC was criticized and new standard curves including only working costs were desired.

All the interviewed were pleased to have the tool integrated in one existing portal and there is no need to learn to use any new portal or report. Any new program or web environment would have been a remarkable disadvantage for the tool. Also the fact that maintaining the analysis updated does not require any additional work compared to current situation was seen soothing. Overall the tool was accepted well and all the interviewed saw it as useful at some level and were interested in using it on their work.

6 Discussions and conclusions

Based on literature review and the application testing results earned value management can be applied in residential construction projects and it can offer a new indicator for cost and schedule performance. Based on empiric research current cost and schedule monitoring processes afford all the data needed to formulate the EVM analysis. The data needs only to be processed to form the parameters and graphs essential for EVM analysis.

The main purpose of this thesis was to create an automated system that performs the data collection, processing and visualization. Mainly the data needed was in usable form. For collecting the schedule data small changes needed to be done on how the schedule files are archived and how schedules are planned. The changes needed do not require any additional work compared to normal planning process. To guide the schedule planning on right track a schedule template for residential project was created to be used in upcoming projects. The template includes names and codes for the tasks so that in the future there should not be any variance in the names and task codes of basic schedule tasks. This makes it easier to automatize the monitoring.

Based on collected data earned value and actual cost graphs can be easily drawn but planned value is a bit more complicated. Since planned value graph can currently not be drawn based on detailed planning or payment plans, standardized cost accrual curves were created to operate as a planned value curve. Standardized curves are illustrations of average cost accruals. Therefore, in this application the cost accrual is compared to average cost accrual. It needs to be kept in mind that the average may not be the ideal cost accrual and in this case the average cost accrual is seen as acceptable. To steer the production on more ideal direction the planned value curves can be modified to present the ideal project.

As schedule is monitored and incoming invoices can be tracked the information needed to constitute earned value and actual cost curves is available. The variances to present the cost and schedule performances can be used together with the EVM key parameters to reflect the project's status.

Most of the problems that arose during the testing phase were due to planning production without complying instructions. If the production planning and monitoring is done according to instructions any problems with the application should not occur. While collecting the data for standardized cost accrual curves it was noted that the older the project the more roughly the schedule was planned and monitored. Some of the oldest project didn't have any monitored schedules or only part of schedule tasks were monitored. This indicates that the schedule planning and monitoring has increased its necessity over the years. And based on feedback gathered from practitioners the use of this application can increase the importance of schedule monitoring and moreover the quality of schedule monitoring, because the more accurate the collected data is the more accurate is the outcome of the application.

The created system works as planned and can be used in project monitoring. Collected feedback indicates that the created system offers useful and informative new tool for construction sites to support their cost and schedule management. Construction managers and site engineers accepted the new tool and were willing to use it in their work.

It was noticed that the most accurate and latest planned value curves should always been used to maintain the correlation to actual production plan. With accurate baselines the comparison is reasonable and offers more beneficial information for project's management team. This means that the schedule files must be updated and control actions made when it is noticed that the original schedule can not be met.

The earned value graphs created represent the schedule performance well and changes on production speed and control actions taken can be seen from the cumulative curves. Schedule variance calculated with EVM correlate with the information offered by the control chart. Only difference between time variance and control charts information is that EVM counts in weekends and midweek holidays to schedule variance. This is a factor that needs to be kept in mind while analysing the results of EVM.

Based on the resulted graphs the cost accrual follows the standardized cost accrual curves well except from the battening task. On other tasks the comparison to the standard cost accrual is reasonable and often a direct reason for cost variance can be identified. Warning signals generated by EVM do not necessarily indicate problem. Since the EV reflects the average values the warning indicates that projects cost accrual is deviating from the average. This deviation may not be a problem but the reason for deviation needs to be verified. Sometimes the reason can be just deviating payment plan or early material deliveries but various other reasons that demand actions can also cause the variation. Reasons demanding action can for example be additional work done that is not taken into account at cost estimate, waiting hours not included in cost estimates, wrongly directed invoices and outdated cost estimate.

Since the standard curve of battening had relatively few reference projects and the deviation between reference projects was relatively large the curve is not very reliable. For some reason the battening work was often paid with only few payments and as a task with relatively short duration the date of payment can have enormous effect on how the cost accrual curve is constituted. It was also noted that the control charts of battening were updated roughly and sometimes the task wasn't monitored at all.

6.1 Recommendations for applying EVM

Based on the result of this thesis it can be recommended to apply EVM on management of residential construction project since it offers accurate information about cost and schedule performance of the tasks. It needs to take into account that this tool works best on tasks that are accomplished continuously and are simple to measure in order to monitor the state of completion.

To implement this kind of automated tool first it needs to be ensured that the data about scheduled states of completion, actual state of completion, cost estimate and occurred costs is available in a form that can be systematically be collected from the information systems by the automated system. In order to form the baseline based on previous projects the cost accrual data needs to be collected and the standard cost accrual curves created. After the baseline is set the collected data can be monitored against the baseline.

The latest information about schedule and cost estimates should always be used while determining the baseline for the task to remain the reasonability of monitoring the actual production against plan. While planning the automated system it needs to be made sure that the system can find the newest data and uses it.

If the baseline is composed of the previous projects it needs to be kept in mind that this baseline is the average of previous projects it is not ideal cost accrual. If the cost accrual is wanted to be steered to be more like the ideal the baseline needs to be modified to meet that target and the error-limits should be adjusted as well.

6.2 Theoretical contribution

Prior to this research there were only few recorded applications of EVM in construction industry in Europe and Finnish application were not found at all. This thesis offers now a recorded application of EVM in Finland. It also proves that EVM is applicable and useful in Finnish residential construction industry and it can offer new visualized tool for project management.

In this research the cost accrual and earned value metrics were analysed on task level and control account level whereas most of the previous researches had kept the analysis on project level. This approach offers more accurate information about task specific cost accruals and reveals the problematic tasks while analysing the whole project identification of the problems can be difficult. This proves that EVM can offer useful tool for managing also smaller parts of the entire project.

There was also a lack of information concerning the combination of EVM and LBMS. In this thesis it is proved that EVM and LBMS can be used side by side and EVM can utilize the information provided by LBM. This thesis offers one automated solution for combining these two project management tools.

6.3 Reliability and validity of the research

This chapter presents the possible factors affecting the validity of this research. Different parts of this research and their error factors are evaluated separately.

6.3.1 Literature review

The literature review was based on relevant scientific articles and textbooks. Used references are evaluated to be valid and reliable. Application examples of EVM from Europe or Scandinavia were hard to find but there were many recorded applications overseas. The overseas applications are assumed to be good and valid examples to implement the theory in Finland too. It can not be assumed that the construction management is similar in U.S as it is in Finland, but the model for applying EVM is assumed to be valid in both countries.

There is only one paper found about applying EVM in a construction project that utilizes location-based management system. This creates uncertainty of the connectivity of EVM and LBMS. This also raises suspicion whether the LBMS fills the need for EVM, because there is not any other recorded use of them side by side.

6.3.2 Empirical research

The ERP-system and the instructions it contains can include outdated information since some of the instructions are updated last time at 2013. Some procedures can be changed and new ways of managing costs and schedules can be developed that are not updated to the system. Also the schedule planning manual is updated last time at 2009. Mainly the manual for schedule planning should still be valid, but there may be some outdated information included.

In the interviews it is possible that some interviewees told how things should be done, not how it is actually done. This was tried to avoid by asking the question in forms that encourage to answer truthfully how they perform. But it is still possible that answers tell more about the way projects should be managed.

6.3.3 Application and testing results

For the determination of standardized planned value curve one major source of error is the way of determining the rate of completion. Now was assumed that in reference projects the completion of task was proceeding linearly between start and end dates and there was no interruptions or changes in production rate that would have made the production non-linear. As was noticed from the test projects only seldom the production is planned to be totally continuous over the whole task and even if it is planned to be continuous the real production often isn't. Even tough clearly anomalous projects were excluded from the data, this factor is the major source of error. This could have been avoided by calculating the exact stated of completion based on control charts and using this data to determine the standard curves. Since this method would have taken a lot more time and the data wasn't available for most of the previous projects the more simple method was used.

Another source of error is that in some cases control chart was used roughly and the dates logged on the chart may not be the actual start and end dates of the schedule task. This is due to the manner of marking tasks begun or ended on the date the activity is noticed, not the day it actually is happened. This generates error in initial data and affects error in final standardized curve too.

The errors in standardized cost accrual curves causes the largest errors on earned value analysis results. Also the manner of updating control charts has an impact of how accurate information EVM analysis can provide. It must be kept in mind that the more precisely the control chart is updated the more accurate the information offered by EVM application is.

Because of the payment delay and invoice acceptance procedures the costs are accumulating with a delay when compared to work performed. This seems like a source of error, but actually the standardized cost accrual curves take this into account. Every projects included in the base data of cost accrual curves have the invoice delays too and therefore the curve includes the delays. But the payment times have lengthen during the years of analysed projects. This may affect small deviation since the change in payment time is not that extensive.

With these tasks the analysis works well. By analysing tasks that are more discontinuous, difficult to monitor and continue over the whole life of the project the results could be more complicated. Based on this research the analysis works on independent tasks that can be monitored easily and the costs are accounted on one control account. With more nonspecific tasks the analysis can provide inaccurate information.

With more test projects the validity of this research would have been higher. In these three cases used there were some variation while Borgiströminmäki was noticeably late from the plan, Perilänniitty was slightly ahead and Kaskelantie was proceeding mostly according to the plan. In these cases the analysis performed described the proceeding of the actual production well. With more case projects more information could have been gathered and evaluated and some other problems could have occurred.

6.4 Suggestions for further research

Currently EVM theory includes cost and schedule. Quality is tightly bound with both costs and schedule and lately the quality of construction has been one of the major discussion topics in the field of construction and in public discussion. Need for combining the quality to performance evaluation is real. A way for evaluating quality along with costs and schedule should be researched. This could be performed by including earned quality graph. Earned quality graph should indicate how much of the performed work is inspected and fulfilling the quality requirements. Then comparison to earned value would then indicate how much of completed work there is to be repaired.

The created EVM system can be used to collect data points which include the state of completion and accumulated costs on a specific date. This data could be used to determine more accurate cost accrual curves for EVM analysis. The collected data also makes it possible to compare production rates between projects. This comparison can reveal new information about factors affecting the production rate and can be helpful on planning schedules for upcoming projects. This allows also the analysis of changes in production rates and the reasons affected the work to speed up or slow down.

While collecting the practioners' feedback a desire for cost accrual curves including only cost classes that consist work. New cost accrual curves for tasks that include material order and work order could be developed. These curves would not include the material's part of the control account. By using these curves the variation caused by early material deliveries if neglected and following the costs of work is simple. Also curves for other tasks and control accounts were asked and idea of determining cost accrual curves for all control accounts came up. This idea could include possibility to create the whole projects or separate main groups cost accrual as a sum of cost accruals of included control accounts.

To make the planned value curves more reliable and project specific, one of the possible ways to is to determine PV according to payment plan. In the purchasing portal exists already a table for payment plan but only few of the purchasers use it. And currently there is no way to get the information out from the purchasing portal. In the future when the way of getting information automatically is out, better planned value curves could be determined by calculating the figure planned cost accrual according to payment milestones and planned completion rates. This offers a possibility to create project specific planned value curves as Alvarado et al. (2005) and Seppanen et al. (2005b) have described. The possibilities of BIM models including schedule and cost data offer should be assessed.

Better ways for examining the physical states of completion should be researched. Currently the monitoring is slow since the control chart can't be updated with mobile devices during the site tour but site engineer's must take notes and update the chart at the office. Some kind of mobile applications or totally another ways for tagging tasks started and done at certain locations should be developed. Some kind of applications using RDIF-tags or machine vision should also be researched since it would offer more real time information than current ways and ease the workload.

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